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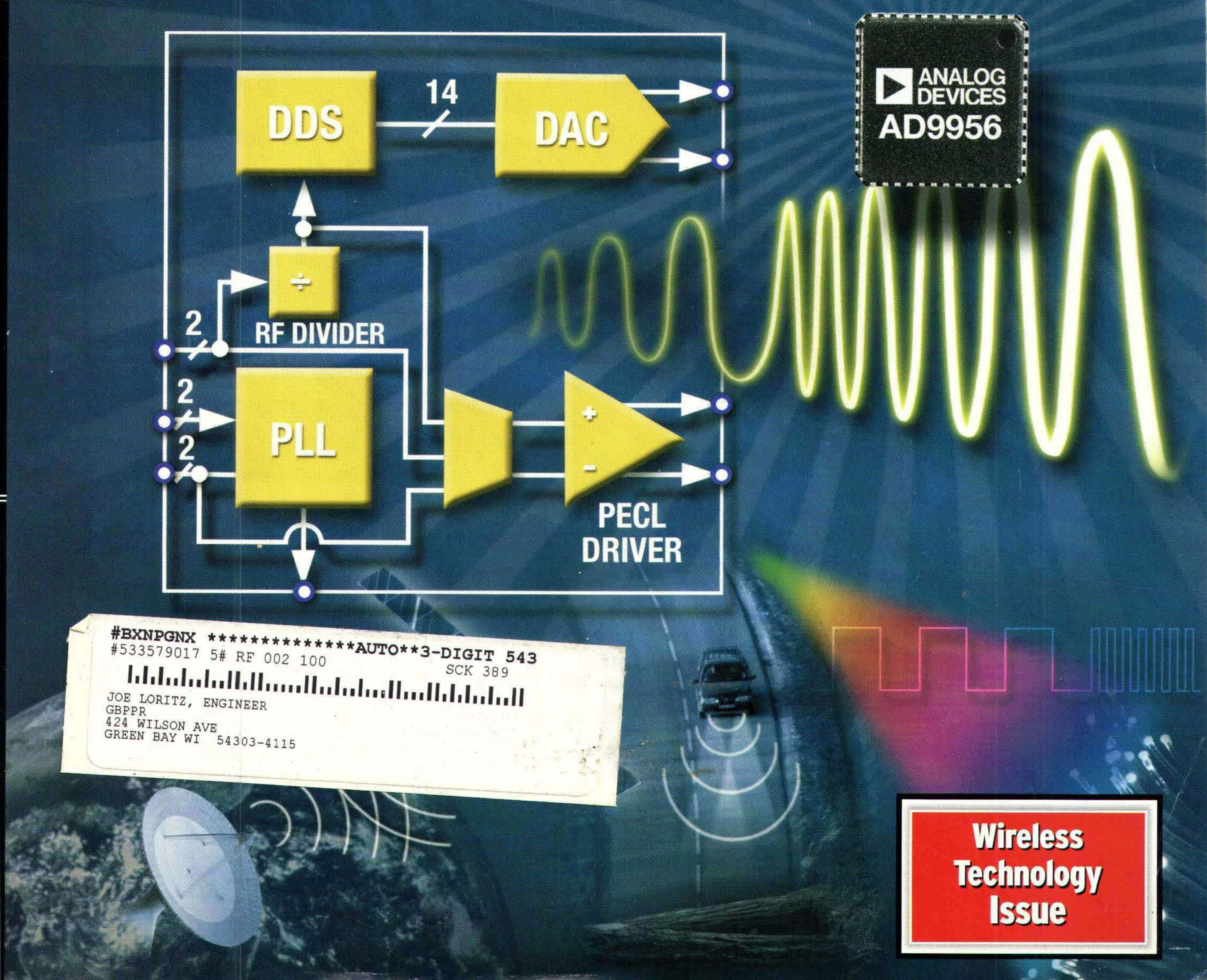
Microwaves & RF

News
Wrapup of the Wireless Conference & Expo

Design Feature
Tracking terrestrial multipath fading

Product Technology
Miniature module melds amp and filter

Integrated DDS Steps To 2.7 GHz



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Wireless Technology Issue

Two good

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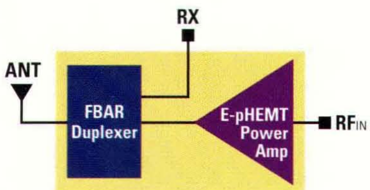

CDMA 1900 FEM Example Block Diagram

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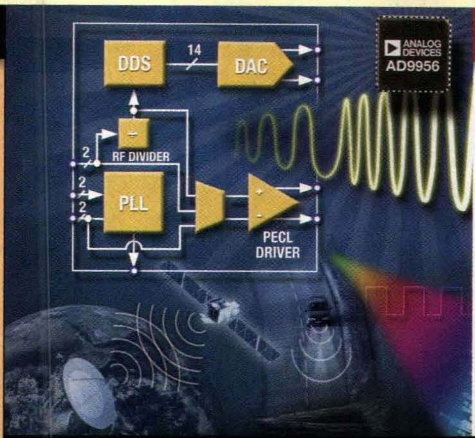
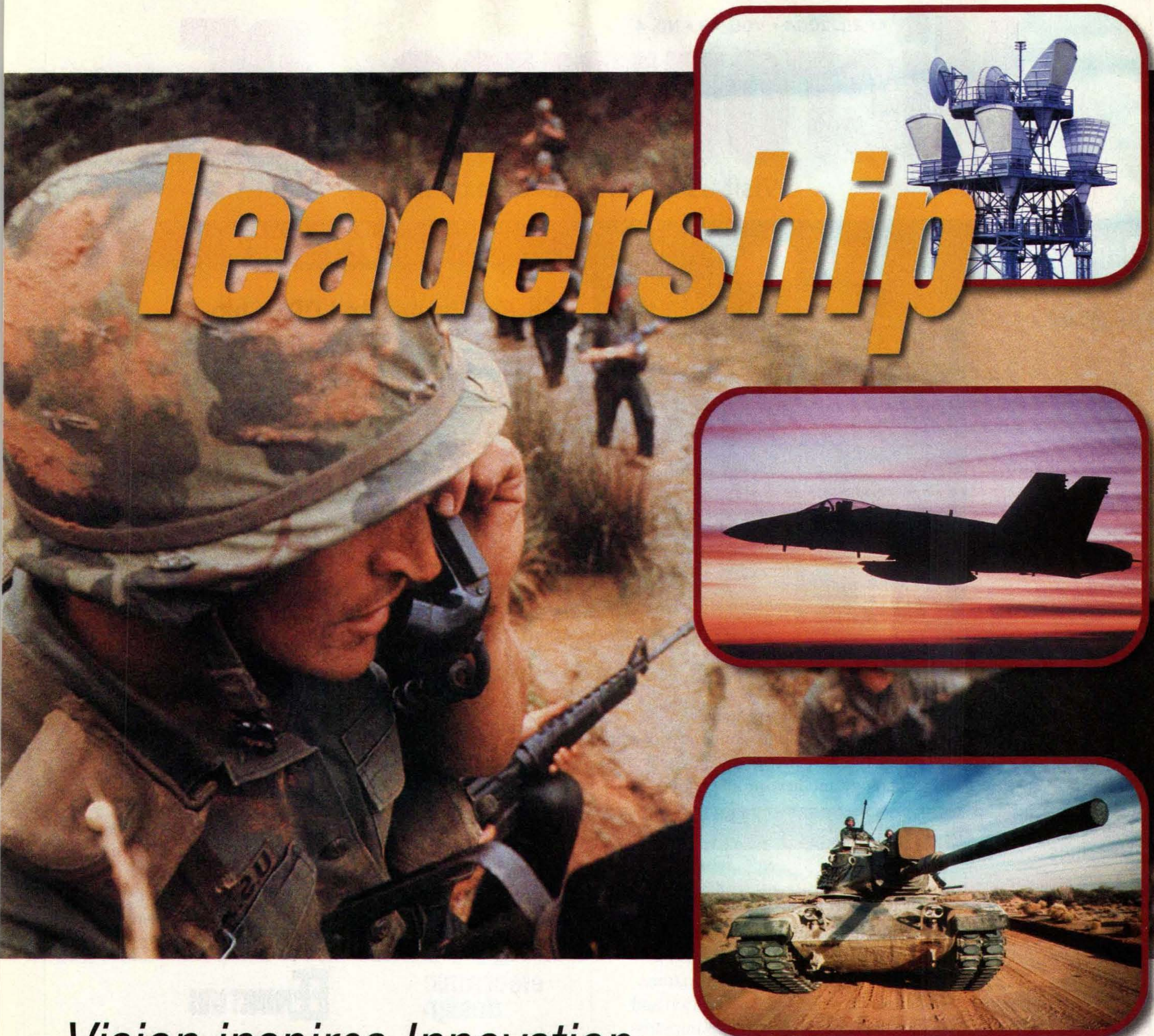


COVER STORY

News

Design

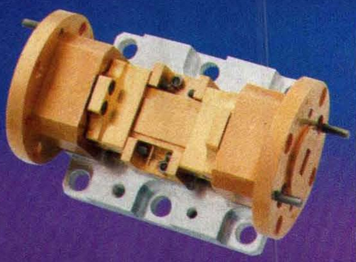
Product Technology


leadership

MILLIMETER WAVE

COMPONENTS

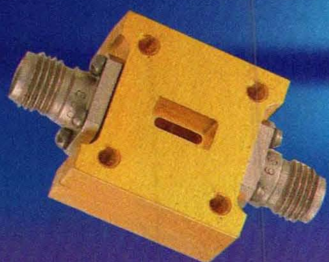
AMPLIFIERS • MIXERS • MULTIPLIERS



AMPLIFIERS

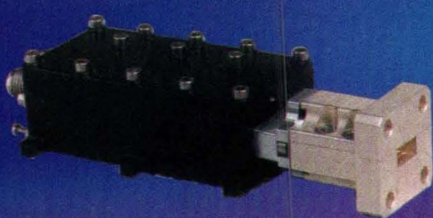
Model Number	Frequency (GHz)	Gain (dB, Min.)	Gain Flatness (±dB, Max.)	Noise Figure (dB, Max.)	In/Out VSWR (Max.)	Output Power at 1dB Comp. (dBm, Typ.)
JSW4-18002600-20-5A	18-26	34	1.5	2.0	2.0:1/2.0:1	5
JSW4-26004000-28-5A	26-40	25	2.5	2.8	2.2:1/2.0:1	5
JSW4-18004000-35-5A	18-40	21	2.5	3.5	2.5:1/2.5:1	5
JSW4-30005000-45-5A	30-50	21	2.5	4.5	2.5:1/2.5:1	5
JSW4-40006000-55-0A	40-60	16	2.5	5.5	2.5:1/2.5:1	0

Higher output power options available



MIXER/CONVERTER PRODUCTS

Model Number	Frequency (GHz)			Conversion Gain/Loss (dB, Typ.)	Noise Figure (dB, Typ.)	Image Rejection (dB, Typ.)	LO-RF Isolation (dB, Typ.)
	RF	LO	IF				
LNB-1826-30	18-26	Internal	2-10	42	2.5	20	45
LNB-2640-40	26-40	Internal	2-16	42	3.5	20	45
ARE3436LC1	34-36	15.5-16.5	2.7-3.3	25	4	20	60
SBW3337LG2	33-37	33-37	DC-4	-7.5	8	N/A	25
TB0440LW1	4-40	4-42	.5-20	-10	10.5	N/A	20
DB0440LW1	4-40	4-40	DC-2	-9	9.5	N/A	25
SBE0440LW1	4-40	2-20	DC-1.5	-10	10.5	N/A	20



MULTIPLIERS

Model Number	Frequency (GHz)		Input Level (dBm, Min.)	Output Power (dBm, Min.)	Fundamental Feed Through Level (dBc, Min.)	DC current @+15VDC (mA, Nom.)
	Input	Output				
MAX2M260400	13-20	26-40	10	10	18	160
MAX2M200380	10-19	20-38	10	10	18	200
MAX2M300500	15-25	30-50	10	10	18	160
MAX4M400480	10-12	40-48	10	10	18	250
MAX3M300300	10	30	10	10	60	160
MAX2M360500	18-25	36-50	10	10	18	160
MAX2M200400	10-20	20-40	10	10	18	160
TD0040LA2	2-20	4-40	10	-3	30	N/A

Higher output power options available

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A Note Of Appreciation

▶▶I WOULD LIKE to thank the staff of *Microwaves & RF* for helping us make our 36-page catalog a reality in your January 2004 issue. Pollybagging our catalog with the January 2004 issue of *Microwaves & RF* has really strengthened our brand and sales in the USA. The response that we have experienced has far surpassed our expectations. As soon as the catalog hit the streets with your January issue, we have had many inquiries. These inquiries continue to this day. The investment was well worth it, and we look to run more inserts in the future.

Thanks again to the team at *Microwaves & RF* for making this the most successful marketing initiative that we have ever undertaken.

Makoto Nakahara
President and CEO
Advantest America Measuring Solutions, Inc.

Editor's Note: Thanks to Advantest for the positive feedback regarding the catalog. We look forward to working with Advantest in the future.

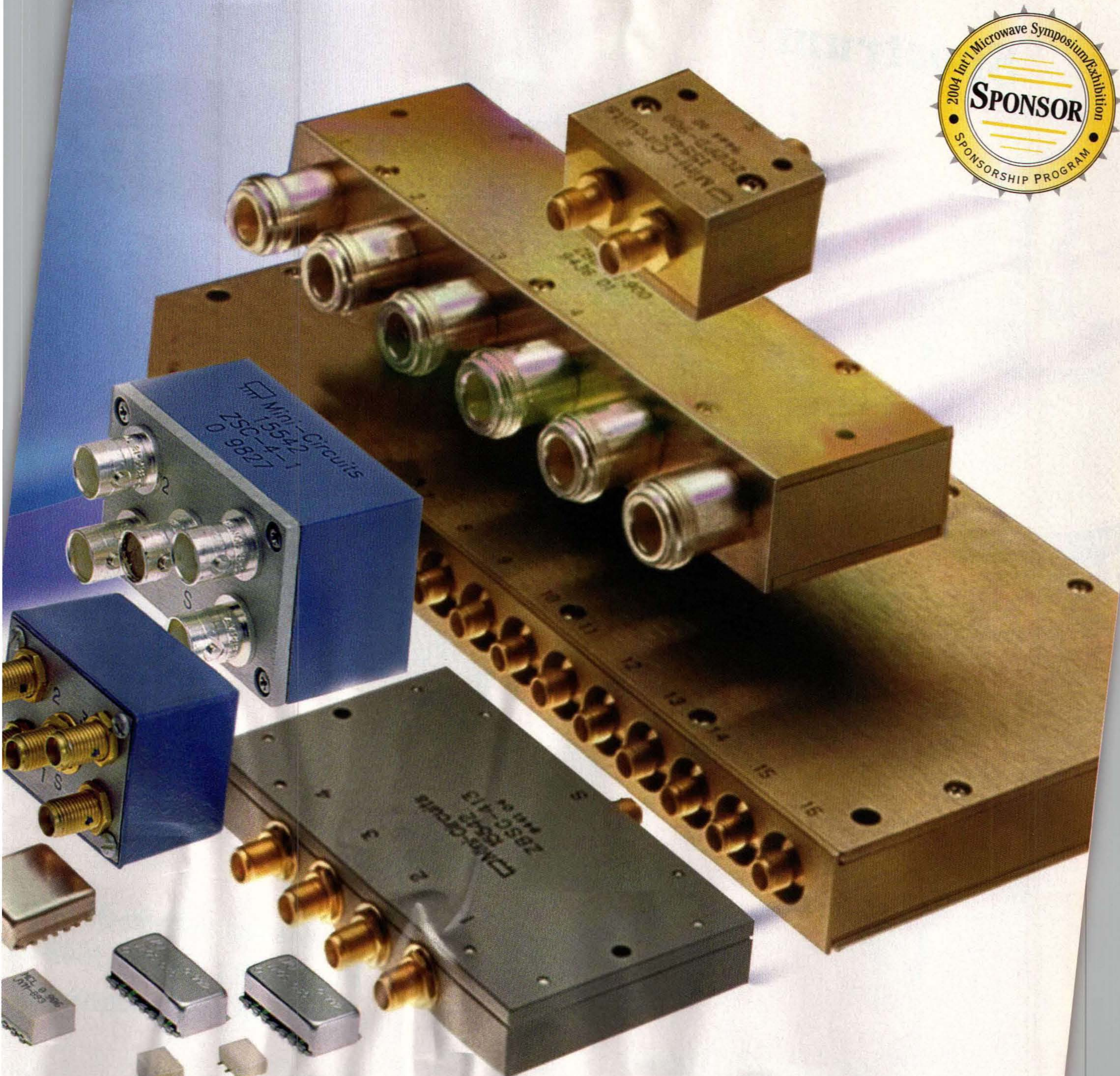
Article Correction

▶▶LET ME PLACE a brief note regarding the sidebar on RKE CMOS ICs by Tarlton Fleming in the March 2004 issue of *Microwaves & RF*, p. 62. In this sidebar, it is stated that Maxim's MAX1472 would be the world's smallest transmitter of its type, housed in an 8-pin SOT23 package measuring 3 × 3 mm. This is not quite true because Melexis is offering a line of RF transmitters housed in an MLP (micro-leadframe package) measuring the same 3 × 3 mm. These transmitters have already been introduced to the market through several press releases in the fourth quarter of 2003.

The following is a partial quote from the press release: "Melexis' new 300-to-930-MHz transmitter-chip family, consisting of TH72005, TH72015, and TH72035, is the world's first low-power and low-cost RF transmitter line packed in the very tiny MLP package. They enable designers to perfectly match their system requirements by each application's frequency range, modulation scheme, and output power requirement. This new automotive qualified line has been specifically designed for applications in the unlicensed industrial-scientific-medical (ISM) and short-range-devices (SRD) frequency bands."

Dr. Andreas Laute
Business Unit Manager
Wireless Communication
Melexis GmbH

Editor's Note: Dr. Laute's letter refers to the sidebar of the article "Steering Through RKE Requirements," March 2004, p. 59.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RF/IF Designer's Guide

Making A Better Microwave Show

MIDYEAR IS RAPIDLY approaching and, with it, preparations for the industry's largest conference and trade show, the IEEE Microwave Theory & Techniques Symposium (MTT-S). Scheduled for June 6-11, 2004 in Fort Worth, TX, the 2004 International Microwave Symposium (IMS) is a full week of tutorials, workshops, panel sessions, technical sessions, and interactive forums as well as a large exhibition floor that currently boasts well over 400 exhibitors. Can it possibly get any better than this?

Why don't more industry companies contribute technical presentations?

In addition to the IMS technical sessions, the week's events include the 2004 IEEE Radio Frequency Integrated Circuit (RF IC) Symposium (June 6th through 8th) and the Automatic RF Techniques Group (ARFTG, June 11th). Sponsored by the IEEE, the 2004 IMS will draw participants from all corners of the globe. But is the MTT-S conference really representative of the microwave industry's latest capabilities?

One of the truly positive and sustaining actions on the part of the IEEE MTT-S and its organizers is to invite student papers and participation. In fact, a student paper competition is held at MTT-S. In 2004, a total of 292 student papers were submitted, with 141 selected for presentation and 26 voted as finalists. The 26 finalists receive complimentary registration for the IMS as well as some help with their travel expenses (from the IMS as well as from the National Science Foundation). The six top presentations and four honorable mentions will receive cash awards, certificates, and gifts in recognition of their achievements. Schools represented in the competition include the University of California at San Diego, University of Illinois at Urbana-Champaign, and Yonsei University (Korea).

In each technical session, these papers are clearly indicated as student papers. Unfortunately, throughout the remainder of the technical sessions, colleges and universities—rather than industry companies—contribute an inordinate number of papers to the 2004 IMS. While it is true that many of these schools perform research at the behest (and funding) of industry companies, many of the topics represent experimental prototypes that may never see a production line.

Why don't more industry companies contribute technical presentations? Some fear disclosing too much information to their competitors, while others cite an unwillingness to devote valuable engineering time to a presentation, which may not lead to more business. When queried, many companies expressed interest in more tutorial and applications-based information (but without overt sales "pitches") at the MTT-S or a show like it. Is the MTT-S/IMS an ideal microwave show, or is there room for another, different type of microwave event? Send an e-mail with your thoughts to jbrowne@penton.com.

Jack Browne

Publisher/Editor

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856182	1220	10	3.8x3.8mm
856183	1220	8	3.0x3.0mm
856184	1220	8	3.8x3.8mm
856365	1216	8	3.0x3.0mm
856382	1120	32	3.0x3.0mm
856096	1090	10	3.8x3.8mm
855964	1086	10	3.0x3.0mm
856257	1086	10	3.0x3.0mm

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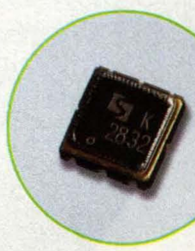
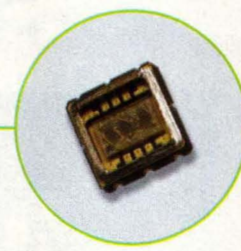


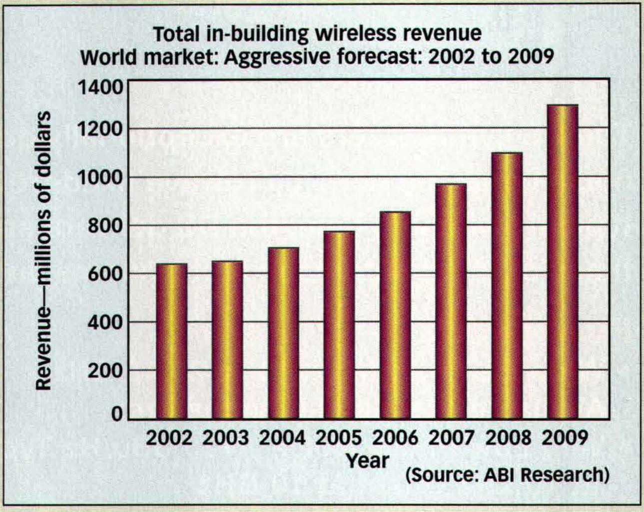


Connecting the Digital World to the Global Network

Distributed Antenna Systems Help Make In-Building Wireless Market A Reality

OYSTER BAY, NY—Prior to the development of in-building wireless (IBW) networks, in order to access the cellular network from inside a building one had to hope that the local cellular carrier's network could penetrate the exterior and interior walls of the building from the outside. More often than not, this simply meant that one went outside to make or receive a call.

In the late 1990s, companies popped up offering IBW solutions to building owners and carriers. In the simplest of models, these companies would negotiate an exclusive arrangement with a building owner to develop the IBW network. This solutions provider would then sell access to the network, usually at rather costly prices, to the highest-paying cellular carrier. This moldel worked in some cases, but it had two inherent problems: (1) the carriers sometimes refused to pay the IBW provider's fees and instead focused spending on their own networks; and (2) the technology for the initial IBW solution was often a clunky and unreliable passive network of coaxial cable and repeaters.



Distributed antenna systems (DAS) is considered a solution to the problems listed above. DAS use fiber cable within buildings to actively distribute signals to a network of small powered antennas. A market for IBW solutions based on DAS has been steadily growing and ABI Research found in an analysis on the subject that the market stands to top $1 billion annually by 2010 **(see figure)**.

QUALCOMM Completes CDMA2000 1xEV-DO Trial With IBM

ATLANTA, GA—QUALCOMM, Inc. has announced the completion and results of a successful CDMA2000® 1xEV-DO pilot program with IBM. The three-month trial, involving IBM sales representatives in the San Diego, CA and Washington, DC regions equipped with CDMA2000 1xEV-DO-enabled laptops, enabled the sales executives to spend on average 2.9 more hours a week with customers. Furthermore, CDMA2000 1xEV-DO allowed IBM sales executives to lower access costs while traveling and gave them the flexibility to respond to customers more efficiently and quickly.

Using a device or laptop, with WebSphere Everyplace Connection Manager (WECM), IBM's mobile employees are able to move from location to location enjoying secure, high-speed access to information when roaming across wireless networks, without interrupting web connections or losing an existing session.

In a survey conducted by IBM, the sales force reported an increase in productivity and an overall high service satisfaction. More than 75 percent of sales executives who used the high-speed, high-capacity wireless service reported satisfaction both in how quick and easy a CDMA2000 1xEV-DO connection was established for their devices, and in how the technology improved a demanding, travel-intensive work routine.

Sales team members cited the ubiquity and speed of CDMA2000 1xEV-DO as the main benefits of using the technology. IBM representatives were able to work where they previously had been unable to, such as on a train.

IEEE Communications Society Honors Dr. Irwin Mark Jacobs

SAN DIEGO, CA—Dr. Irwin Mark Jacobs, chairman and CEO of QUALCOMM, Inc., has been named this year's industry leader by the IEEE Communications Society.

"Dr. Jacobs exemplifies the mission of of the IEEE Communications Society, which is to promote the advancement of science, technology, and applications in communications and related disciplines," comments Curtis A. Siller, Jr., president of the IEEE Communications Society. "His executive leadership of QUALCOMM has resulted in advances and new directions in the information and communications industry. The IEEE Communications Society is pleased to recognize this contribution with our Industry Leader Award."

"Dr. Jacobs' leadership has resulted in advances and new directions in the information and communications industry."

Dr. Jacobs received the honor for his contribution to and leadership in the development and growth of the wireless-communications industry. Dr. Jacobs has guided code-division multiple access (CDMA) through its success as the world's fastest-growing, most advanced voice and data wireless technology.

"I'm honored to be recognized by the IEEE Communications Society and to be in such excellent company with past award winners," says Dr. Jacobs. "QUALCOMM is pleased to be recognized for its innovations in CDMA technologies and contributing to the wireless industry as a whole."

Dr. Jacobs founded QUALCOMM in 1985, and has served as the company's chairman and CEO since its inception.

TÜV America Renovates EMC Testing Lab In Minnesota

NEW BRIGHTON, MN—TUV America has announced the completion of renovations at their EMC Open Area Test Site (OATS), located in Taylors Falls, MN.

Renovations include new upgrades to the facility including a new ferrite-lined immunity chamber, which provides clients radiated immunity testing capabilities that meet European and FDA requirements. Also included within the renovations is a redesigned and spacious front office as well as cosmetic updates to two emissions test planes located at the facility.

"Overall, the renovations provide significant upgrades to the lab and the ability to offer complete immunity and emissions testing under one roof," states Kevin Larson, EMC product director at TUV America. "TUV is committed to investing in our facilities, to enhance the clients' testing experience while increasing testing capabilities with new equipment, personnel, and chambers."

The Taylors Falls Laboratory is one of three TUV owned and operated labs in Minnesota. The others are in New Brighton and Oakwood.

AR Worldwide Aids Schoolkids With Student Science Organization

SOUDERTON, PA—AR Worldwide CEO Donald (Shep) Shepherd is a firm believer in the fact that children need positive role models. Shepherd feels that it is important for kids to look up to those individuals who create things and solve problems, like engineers and scientists.

When AR was approached over eight years ago to sponsor a high-school science and technology team, Shepherd leaped at the opportunity. AR provides the majority of the team's funding, and AR personnel work closely with the team as mentors and coaches. The result has been very rewarding for everyone involved.

The team, which is involved in scientific projects that build self confidence, knowledge, and life skills, is part of the international youth organization, FIRST (For Inspiration and Recognition of Science & Technology). Known as Cybersonics, the team from Palisades High School in Kintersville, PA, has won numerous awards over the years, including the highest honor in an international student competition sponsored by FIRST in 2003.

Throughout the past eight years, the Cybersonics team has developed a strong relationship with AR, and the people from AR have been very pleased to see the high-school team members grow intoproductive adults who are now positive role models themselves.

The experience has been so positive for the high-school students that the team is now sponsoring an elementary-school program so that fourth, fifth, and sixth graders can benefit from the FIRST organization's programs.

"It's a wonderful thing to see these students develop the confidence and the life skills necessary to become the leaders of tomorrow," Shepherd says. "We are so proud of these young people and so pleased to be a part of something so uplifting."

MDS Will Provide Wireless Radio System To Local Police

LAS VEGAS, NV—Microwave Data Systems (MDS), a firm involved in industrial, wireless, networking solutions with applications in the supervisory-control and data-acquisition (SCADA), public-safety, telecommunications, and online transactional markets, together with full-service partner Twin Cities Industrial Control (TCIC), has announced that it will provide a wireless radio system to the City of Woodbury, MN Police Department.

This new mobile-communications network will have MDS iNET 900® radios installed in their police vehicles, connecting officers with the city's network. The new system will streamline processes and increase efficiency by enabling officers to submit reports and complete other paperwork remotely from their vehicles.

The addition of the MDS iNET radios means that officers now have real-time access, directly from their vehicles, to information from various local sources including the Minnesota Department of Motor Vehicles.

> *"Security, throughput, and cost savings were all factors that led to the selection of the MDS iNET."*

Security, throughput, and cost savings were all factors that led to the selection of the MDS iNET. A city-owned, private, wireless network means no recurring monthly fees unlike many other wireless solutions. In addition, the combination of speed-512 kb/s-and range also surpasses most off-the-shelf 802.11b solutions.

Another important consideration for the city's network was security, since it would be interfacing with government networks and information. The MDS iNET provides multiple security levels, such as encryption and key rotation, to prevent eavesdropping and unauthorized access to a network.

Kudos

HUDSON, MA—Accumet Engineering Corp., a Massachusetts-based company specializing in ultra-precision service for lapped and polished dielectric substrates, announced today that their commitment to high customer service, continuous improvement, and technical excellence has earned them company-wide ISO 9001:2000 certification through the certification body of TUV America, Inc.

IRVING, TX—Elcoteq Network Corp., global provider of electronics manujfacturing services (EMS) for the communications technology industry, announced that Elcoteq, NPI Dallas won a 2004 Service Excellence Award (SEA) in the technology category. The 2004 SEA for Electronics Manufacturing Services Providers was sponsored by *Circuits Assembly* magazine and announced during a ceremony at APEX 2004 in Anaheim, CA. This highly acclaimed annual award recognizes the companies that receive the highest customer service ratings as judged by their own customers.

VISTA, CA—Palomar Technologies, a manufacturer of automated, high-precision assembly systems, was honored as one of the top 25 San Diego stars of commerce at the *San Diego Business Journal's* sixth-annual Stars of Commerce STARCOM awards dinner on March 24, 2004. Criteria for receiving the award included profitability, product, corporate ethics, innovation, and commitment to employees and community.

NEENAH, WI—Plexus Corp. has been awarded the 2004 Overall Service Excellence Award in the Large Company category (annual revenues over $500 million) for Electronics Manufacturing Services (EMS) providers. This is Plexus' fourth-consecutive Overall Service Excellence Award.

GREENSBORO, NC—RF Micro Devices, Inc., a provider of proprietary RF integrated circuits (RF ICs) for wireless-communications applications, announced that Market Intelligence Center has recognized RF Micro Devices as Taiwan's leading provider of power amplifiers (PAs) for wireless handsets.

According to a March 2004 report titled, "The Taiwanese Mobile Phone Industry, 2003 and Beyond," Market Intelligence Center (MIC) estimated that RFMD's market share in Taiwan grew from 23.1 percent in the fourth quarter of 2002 to 73.2 percent in the fourth quarter of 2003, an increase of approximately 216 percent.

WASHINGTON, DC—A government and industry technical team was recognized by the Defense Department recently for its role in the development of international specifications for the format and structure of electronic technical manuals. The 2003 Honorary Defense Standardization Program (DSP) Achievement Award was presented to the Interactive Electronic Technical Manual (IETM) Industry Specification Team by DoD's Standardization Program Office at its annual conference in March. The IETM team is composed of The Boeing Co., the Naval Surface Warfare Center Cardcrock Division, and the US Air Force Materiel Command. MRF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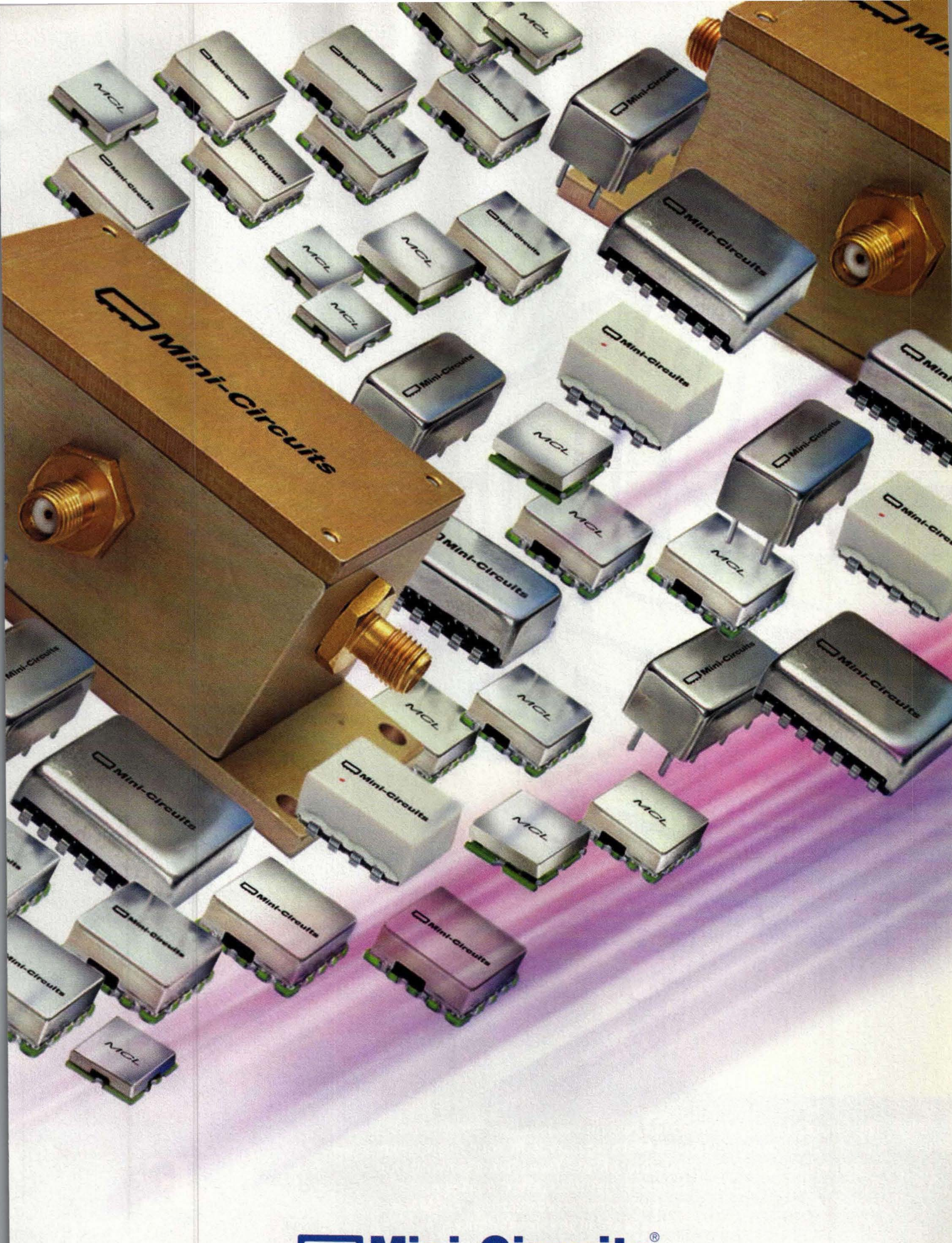
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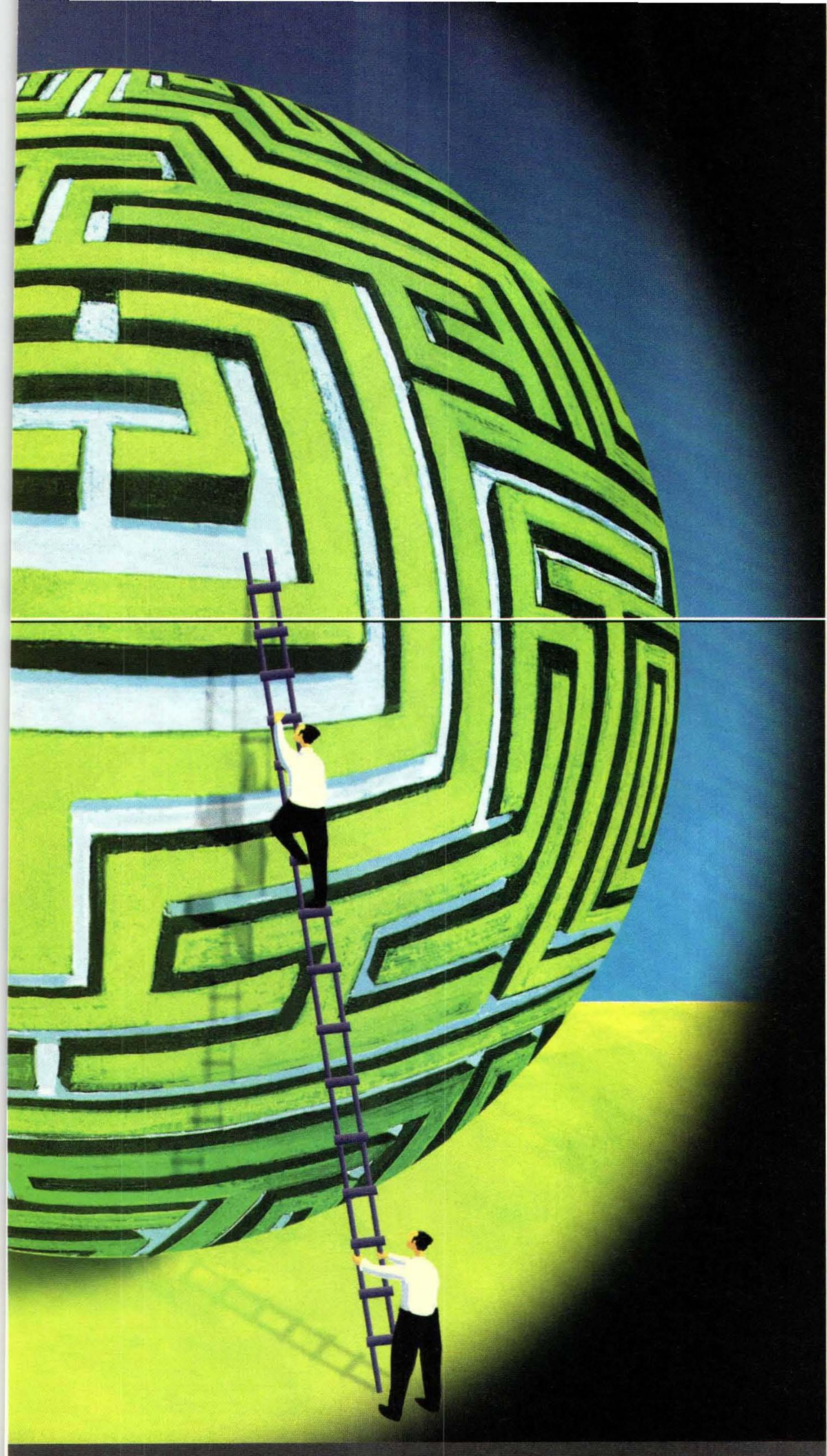


San Diego Show Draws Wireless Designers

Held for the first time in San Diego, the Wireless Systems Design Conference & Expo marked its 12th year with a strong selection of technology and new-product launches.

JACK BROWNE
Publisher/Editor

Wireless markets may have slowed over the last several years, but wireless technology continues to advance. Many of the exhibitors at the recent Wireless Systems Design Conference & Expo pointed to aggressive product development programs as their way to break out of a sluggish economy for high-frequency electronics sales. Held March 8-10, 2004 at the San Diego Convention Center (San Diego, CA), the technical conference and exhibition featured technical presentations by some of the leading personalities in wireless technology as well as several new product launches representing significant advances in the current production state of the art.

Held for the first time in Southern California, the three-day event offered several Keynote addresses with different themes. On opening day, Dr. Henry Samueli, co-founder and chairman of Broadcom Corp. offered his views on of the state of present and future wireless markets in a talk entitled "Wireless in Everything: Life in a Fully Connected World."

The following day, Dr. Ronald E. Reedy, founder, vice president, and CTO of Peregrine Semiconductor, switched to a more military theme in his presentation "Managing Mil/Space and Commercial Business in RFICs." In his presentation, he used a two-channel Global Positioning System (GPS) receiver design as an example of a military development program that provided solid business for the company, and was later refined for several commercial products.

In a third Keynote Address, Robert Poor, CTO and co-founder of Ember Corp., projected many of the industrial uses for wireless technology in a talk entitled "The Future of Industrial Wireless: What's on the Horizon and Where the Growth Will Be." His address was part of the first-ever Industrial Wireless Applications Summit (IWAS) technical program within the Wireless Systems Design Conference & Expo. The IWAS featured a strong lineup of technical presentations on industrial applications, and included a tutorial on RF/wireless basics by Mihir Ravel of National Instruments, the migration of wireless technology to the industrial sector by Enrico De Carolis of Numatics, Inc., applications for radio-frequency identification (RFID) tags and readers in industrial applications by Sean Loving of SkyeTek, and the use of RFID technology in fluid tracking and monitoring by Rick Garber of Colder Products.

Technical sessions at the Wireless Systems Design Conference & Expo were offered in numerous tracks, includ-

ing Broadband/Wireless Networks, Handset Design, Power Management, Wireless Security, and Test and Measurement. One of the better-attended sessions explored variations on conventional wireless modulation techniques, such as ultrawideband (UWB) and ultranarrowband (UNB) modulation. In a talk entitled "Understanding and Using Ultra Wideband (UWB)," Jon Adams, director of radio technology for the Radio Products Division of Motorola's Semiconductor Products Sector compared UWB to Bluetooth and other established wireless-communications formats and explores its possible benefits over existing wireless-communications technologies. Roberto Aiello of Staccato Communications reviewed the activities of the Wireless 1394 group in their push toward UWB standardization, while Kursat Kimyacioglu of Philips Semiconductors explored his company's interest in UWB technology for consumer applications.

On the UNB side, Harold Walker of Pegasus Data Systems addressed an early-morning crowd with his review of the sometimes-controversial UNB approach to transmitting information. He was backed by Bohdan Stryzak of Photron Sciences who offered a comparison of UNB and UWB technologies, and detailed how each was suited for a different set of applications.

On the exhibit floor, news on the product-development front came in many shapes and sizes. Atmel Corp. (San Jose, CA), for example, announced a line of power amplifiers based on silicon germanium (SiGe). Models TO905 and ATR0906 are fabricated with a proprietary SiGe process and designed for frequencies of 135 to 600 MHz and 500 to 1000 MHz, respectively. As much as 32 dB power gain can be set dynamically, with as much as +35 dBm output power in CW mode and efficiency as high as 55 percent.

In addition, Atmel announced that its GPS chip set is now equipped with new read-only-memory (ROM) version 3.0 which provides improved navigation accuracy and integrity as well as higher sensitivity. The new ROM allows the chip set to receive Satellite Based Augmentation System (SBAS) signals from multiple geostationary satellites such as the Wide Area Augmentation System (WAAS) satellite in the US and the European Geostationary Navigational Overlay System (EGNOS) in Europe simultaneously. The company's GPS receiver, which employs a 16-channel architecture (compared to the 12-channel approach by many GPS receivers), uses this additional information to improve the navigation accuracy. The chip set's GPS

receiver can track signals as low as –150 dBm.

The Fairchild RF division of Fairchild Semiconductor (Tyngsboro, MA) offered its full range of power amplifiers (PAs) and front-end products for cellular, WLAN, and millimeter-wave applications. The company's model RMPA2550, for example, is a dual-band PA for IEEE 802.11a/b/g WLAN applications at 2.4 to 2.5 GHz and 5.15 to 5.85 GHz. Operating from a single positive voltage, the amplifier provides at least 27 dB small-signal gain in a 3 × 4-mm package. The model RMPA5251 power-amplifier module (PAM) operates over the same two frequency bands and includes power detection and power-shutdown functions with better than +21 dBm output power. The packaged module measures 3 × 3 mm. For single-band use, the company's model RMPA2450 monolithic PA provides +31 dBm output power from 2.4 to 2.5 GHz with PAE of 35 percent at +7 VDC and +28 dBm output power at +5 VDC.

Fujitsu Microelectronics America (Sunnyvale, CA) introduced three single-serial-input phase-locked-loop (PLL) frequency synthesizers at the show. The new lineup includes models MB15E05SR, MB15E06SR, and MB15E07SR, with frequency ranges to 2.0, 3.0, and 2.5 GHz, respectively. The PLLs feature a separate charge-pump power-supply pin and the ability to operate on voltages as high as +5.5 VDC, making them ideal for a broad range of wireless applications. For example, model MB15E07SR has a 2.5-GHz prescaler and a voltage supply range of +2.7 to +5.5 VDC, drawing just 7.2 mA at +3.75 VDC.

The Wireless Semiconductor Division of Agilent Technologies (San Jose, CA) launched a front-end module combining two of its key technologies: a film-bulk-acoustic-resonator (FBAR) filter and a GaAs enhancement-mode pseudomorphic high-electron-mobility-transistor (E-pHEMT) amplifier. The new model AFEM-7731 front-end module (FEM) is suitable for code-division-multiple-access (CDMA) 1900 Personal Communications Services (PCS) and dual-band cellular handsets. The duplexer is designed for transmit frequencies of 1850 to 1910 MHz and receive frequencies of 1930 to 1990 MHz. The duplexer provides high isolation between the transmit signal path and the receiver port, with receive noise blocking of 44 dB and transmit signal suppression of 54 dB. The duplexer's insertion loss is 2.2 dB in the receive band and 1.8 dB in the transmit band. The amplifier delivers +24.5 dBm linear output power from a +3.4-VDC supply.

On a somewhat larger scale, Anritsu Co. (Morgan Hill, CA) introduced a fully integrated wireless-local-area-network (WLAN) test solution called the model MT8860A. The standard intro-

ductory model performs all receiver and transmitter measurements on all 14 IEEE 802.11b WLAN channels at 2.4 GHz, and can be upgraded to support IEEE 802.11a and g standards at both 2.4 and 6 GHz. The instrument has an internal "golden" reference radio (for comparison to systems under test) and also has connections for an external reference radio. The MT8860A can provide high-speed testing of transmitter power (peak and average, power burst profiles), frequency, carrier suppression, spectrum mask compliance, and harmonic levels.

The integrated test instrument can also perform automated measurements of receiver sensitivity, adjacent-channel rejection, nonadjacent-channel rejection, and receiver saturation. For example, for frame-error-rate (FER) testing, the MT8860A establishes an ad hoc connection with a device under test DUT and transits a user-defined number of frames to the DUT. Under proper operation, the DUT sends an acknowledge frame in return for each received frame. The FER can be calculated from the ratio of transmitted frames to received acknowledge frames.

Making full use of a PC for microwave measurements, National Instruments (Austin, TX) launched its model PXI-5670 three-slot, 3U PXI RF vector signal generator. In spite of its compact module format, the unit is a full-featured RF vector signal generator capable of generating output signals from 250 kHz to 2.7 GHz with 22-MHz real-time bandwidth and a wide range of modulation formats. By programming its 100 MSamples/s (interpolated to 400 MSamples/s) integral 16-b arbitrary-waveform-generation circuitry and as much as 256 MB of on-board memory, the vector signal generator can command a wide range of modulation formats, including amplitude modulation, (AM), frequency modulation (FM), phase modulation (PM), amplitude-shift keying (ASK), frequency-shift keying (FSK), minimum shift keying (MSK), and quadrature amplitude modulation (QAM).

Depending upon the memory option, the vector signal generator can provide frequency resolution as fine as 0.6 Hz while adjusting output levels over a range of –145 to +13 dBm. The typical tuning speed is 35 ms. Typical phase noise is –87 dBc/Hz offset 1 kHz from the carrier in a real-time bandwidth of less than 10 MHz, improving to –114 dBc/Hz offset 100 kHz from the carrier. Nonharmonic spurious content is typically –80 dBc. The PXI vector signal generator ships with the company's Modulation Toolkit for LabVIEW software for generating complex waveforms and modulation. MRF

Vector Generator Fits PXI Module

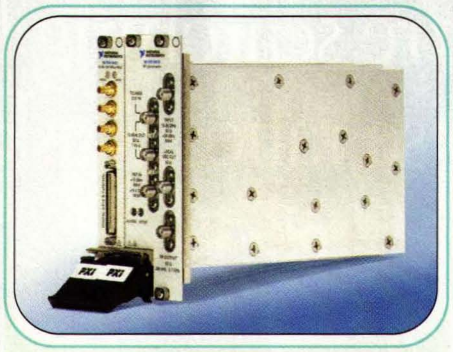
DECEPTIVELY COMPACT WITHIN a three-slot, 3U PXI module, the model PXI-5670 is nonetheless a full-featured RF vector signal generator capable of generating output signals from 250 kHz to 2.7 GHz with 22-MHz real-time bandwidth. By programming its 100 MSamples/s (interpolated to 400 MSamples/s) integral 16-b arbitrary-waveform-generation circuitry and as much as 256 MB of on-board memory, the vector signal generator can command a wide range of modulation formats, including amplitude modulation, (AM), frequency modulation (FM), phase modulation (PM), amplitude-shift keying (ASK), frequency-shift keying (FSK), minimum shift keying (MSK), and quadrature amplitude modulation (QAM). P&A: $12,995 and up; stock.

National Instruments, 11500 North Mopac Expressway, Austin, TX 78759-3504; (512) 683-0100, FAX: (512) 683-9300, e-mail: info@nsi.com, Internet: www.ni.com.

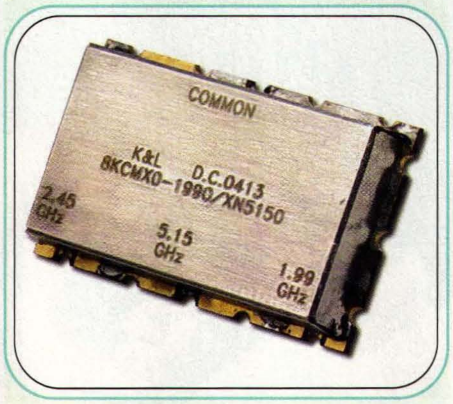
Triplexer Isolates PCS/WLAN Bands

DESIGNED TO SEPARATE different wireless-local-area-network (WLAN) bands, specifically at 2.56 and 5.15 GHz, the model 8KCMXO-1990/XN5150 triplexer provides more than 40-dB isolation. The low-cost triplexer incorporates the equivalent of three filters, with passbands of 800 to 1990 MHz, 2400 to 2500 MHz, and 5150 to 6000 MHz. It measures 1.25 × 0.75 × –0.2 in. in surface-mount form and 1.50 × 1.0 × 0.4 in. in a package with coaxial connectors. The triplexer is ideally suited for separating WLAN and Personal Communications Services (PCS) signals as well as maintaining multiple cellular transmissions on a single antenna.

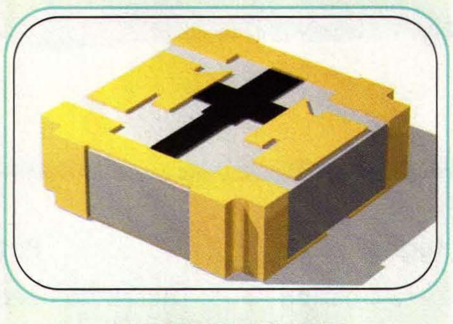
K&L Microwave, 2250 Northwood Dr., Salisbury, MD 21801; (410) 749-2424, FAX: (410) 749-5725, e-mail: sales@klmicrowave.com, Internet: www.klmicrowave.com.



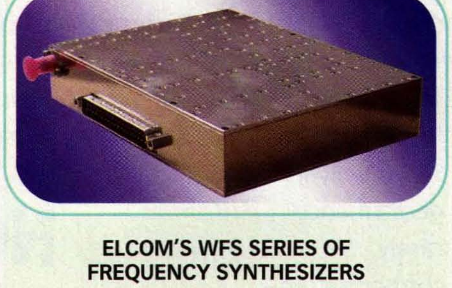
NATIONAL INSTRUMENTS' MODEL PXI-5670 MODULE



K&L MICROWAVE'S MODEL 8KCMXO-1990/XN5150 TRIPLEXER



MICROMETRICS' FIXED ATTENUATOR PADS



ELCOM'S WFS SERIES OF FREQUENCY SYNTHESIZERS

Attenuator Chips Pad DC To 40 GHz

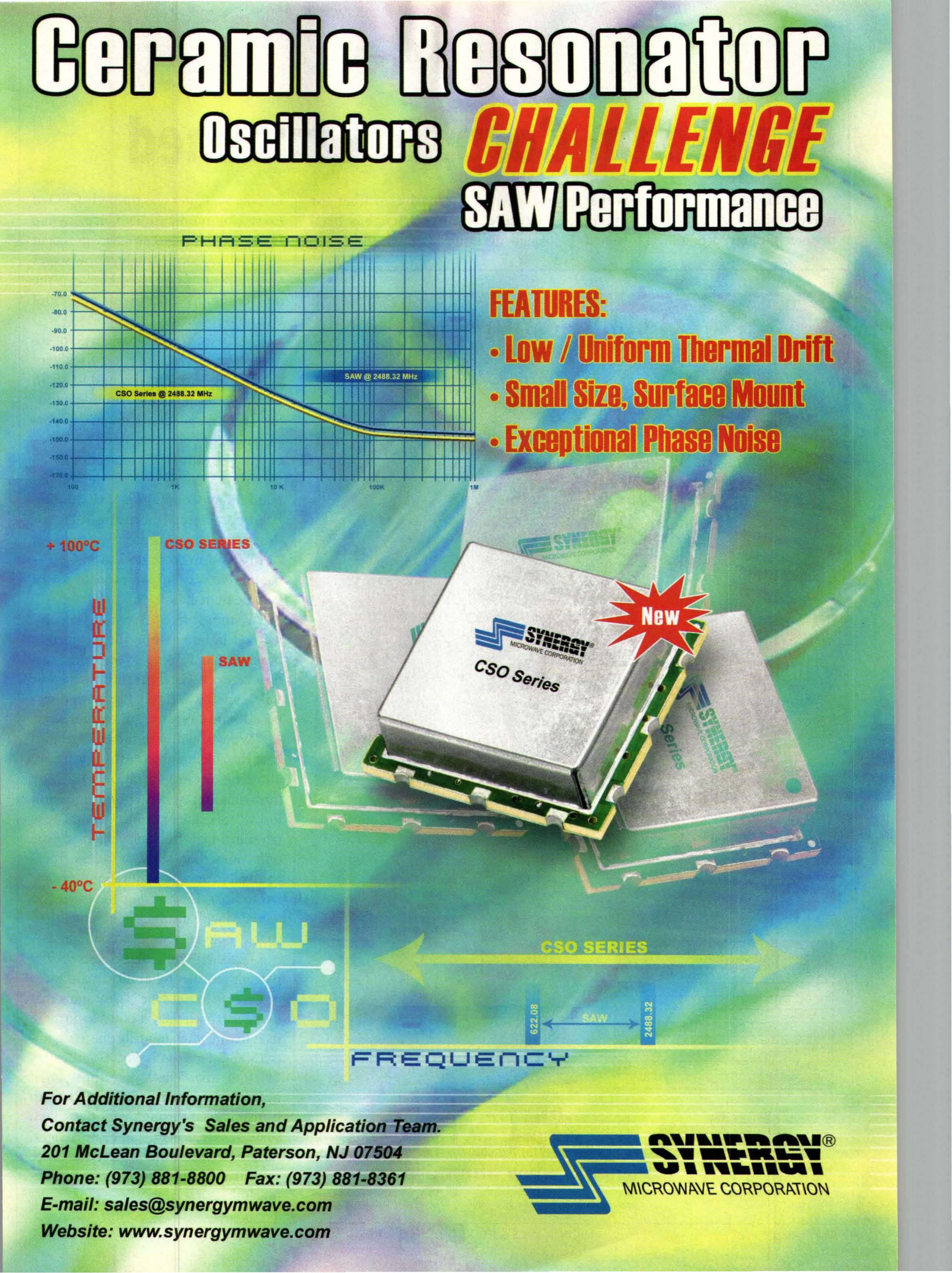
A NEW LINE of fixed attenuator pads feature an innovative GroundWrap design that provides good ground connections without the need for separate ground bonding. The ground is wrapped around the pad's four corners allowing solid ground connections through the use of conductive epoxy or solder performs, rather than additional ribbon bonds. The chip attenuators are available in fixed values from 1 to 30 dB, with additional values available upon request. They measure 0.030 × 0.030 × 0.010 in. (0.762 × 0.762 × 0.254 mm) but handle power levels to 2 W with flat response from DC to 40 GHz. The temperature coefficient of resistance is an impressive 100 PPM. Return loss measures better than 18 dB from DC to 12 GHz and better than 16 dB from 13 to 40 GHz.

Micrometrics, Inc., 54 Grenier Field Rd., Londonderry, NH 03053; (603) 641-3800, FAX: (603) 641-3500, Internet: www.micrometrics.com.

Single Module Holds 3-GHz Synthesizer

THE WFS SERIES of frequency synthesizers are single-module designs based on indirect phase-locked-loop technology. Well suited for radar and automatic-test-equipment (ATE) applications, the frequency synthesizers operate from 1.5 to 3.0 GHz with +13 dBm output power and 120-μs switching speed (and an option for 50 μs). The sources offer 1 kHz frequency resolution (optionally 1 Hz), with spurious outputs to –70 dBc and harmonics of –20 dBc. The phase noise is –110 dBc/Hz offset 1 kHz from the carrier and –130 dBc/Hz offset 1 MHz from the carrier. The synthesizers measure 4.25 × 5.7 ×1.1 in. and weigh 1.2 lbs.

Elcom Technlogies, Inc., 11 Volvo Dr., Rockleigh, NJ 07647; (201) 767-8030, FAX: (201) 767-6266, e-mail: tara@elcom-tech.com, Internet: www.elcom-tech.com.



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GigaBeam Corp. Is Launched

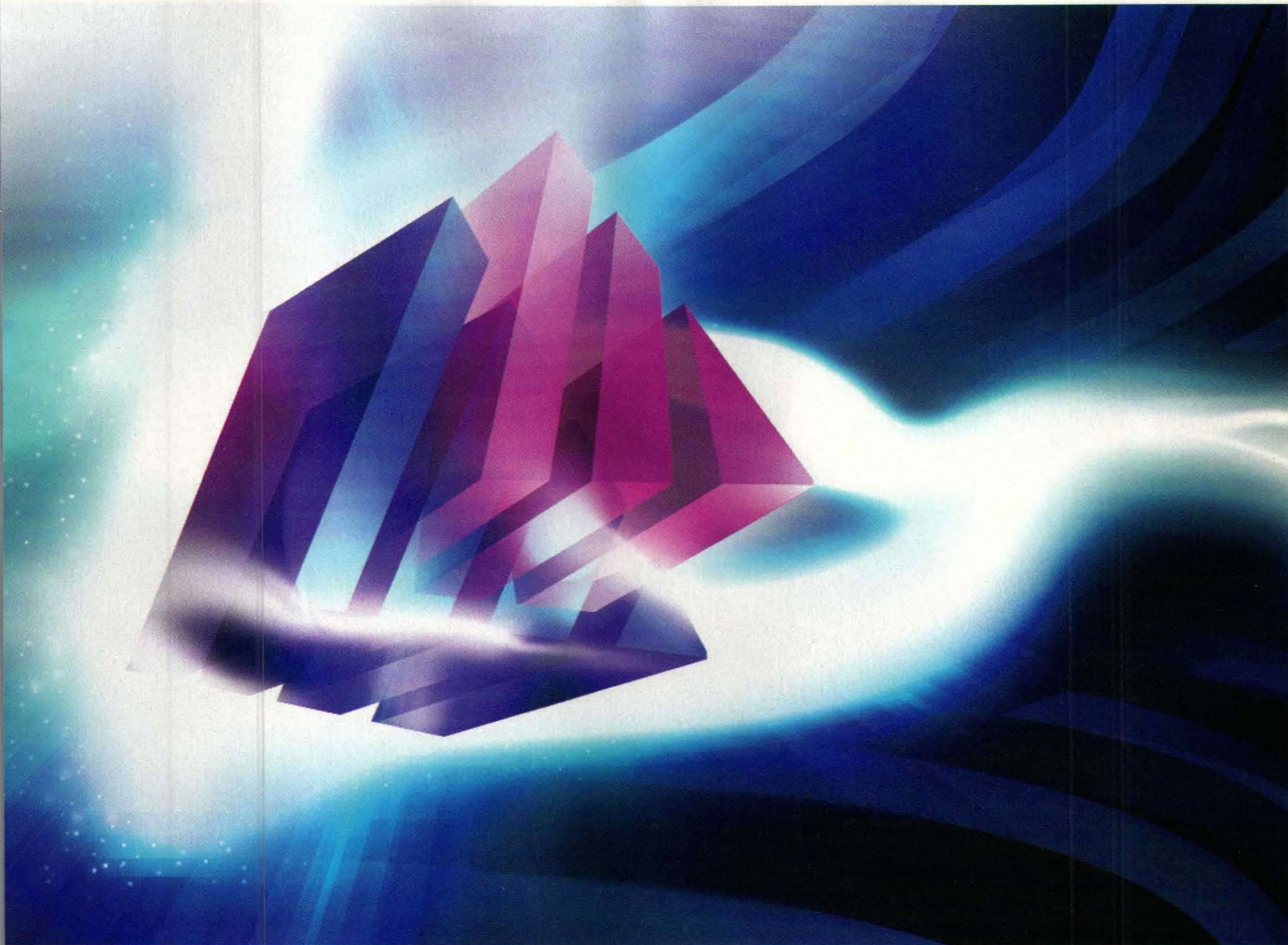
GIGABEAM CORP., a new company that is developing and marketing "virtual" fiber technology, providing a low-cost and feasible alternative to fiber for "last mile" connectivity, has been formed by Lou Slaughter and Doug Lockie. Slaughter was formerly CEO of Loea Communications Corp., while Lockie had been executive vice president at Endwave Corp. Slaughter now serves as GigaBeam's CEO and Lockie is the new company's president and chief technology officer.

GigaBeam's technology is a point-to-point wireless system that uses very high RF at 71 to 76 GHz and 81 to 86 GHz to transmit data at multi-gigabit-per-second speeds. One gigabit-per-second is the equivalent of 647 T1 lines or about 1000 DSL connections. On October 16, 2003, the US Federal Communications Commission (FCC) authorized commercial licensing rules for this very high frequency spectrum—at 71 to 76, 81 to 86, and 92 to 95 GHz—paving the way for widespread use of GigaBeam technology.

"With just five percent of US commercial buildings housing businesses of more than 20 employees linked to a fiber network, GigaBeam bridges the 'last mile' quickly and reliably, with ultra-broadband capacity," Slaughter says.

"We worked with the FCC to pioneer the rulemaking for this spectrum, allowing any organization to deploy multi-gigabit speed communication links," Slaughter continues. "These new ultra-high-frequency bands are the only ones that allow wireless fiber-equivalent speeds with reliability similar to fiber. Lower frequencies are too crowded with insufficient bandwidth to enable multi-gigabit-per-second speeds."

GigaBeam's technology offers 99.999 percent weather reliability at distances of a mile in most of the US, meaning that the system potentially is down to no more than five minutes annually due to weather, Slaughter comments. GigaBeam's "virtual fiber" uses very thin pencil beams of less than one degree that can transmit even through windows. Two small antennae in the same line of sight, positioned on a window inside an office or outside a building, form one wireless link. MRF



From the company that brought you HFSS™...

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CONTRACTS

Aeroflex, Inc.—Has received an order for 83 IFR2975 P25 Radio Test Systems from the Federal Bureau of Investigation (FBI) to test the FBI's new digital radio technology. Designed for bench and field operations, the IFR2975 incorporates advanced test features for secure and classified communication systems. Delivery of the test systems will occur in the next 60 to 90 days.

Rohde & Schwarz—Has been contracted by NEC Australia to supply over 500 type R&S XU250A VHF transceivers. The transceivers will be deployed by Airservices Australia to modernize the air-traffic-control (ATC) system for the entire continent. The transceivers, with a total value of several million euros, are scheduled to be delivered by the end of 2005.

Radstone Technology plc—Was awarded a new contract for $4.5 million from Raytheon Integrated Defense Systems, Tewksbury, MA.

This production contract is Phase 8 of the program and is in addition to the Phase 7 contract that Radstone was awarded in 2002.

EMS Technologies, Inc.—Announced that EADS Astrium has awarded EMS' Space & Technology/Atlanta Division two contracts valued at $6.1 million for key hardware on the United Kingdom's next-generation military communications satellite system, Skynet 5.

The first UK satellite program to be funded through an innovative finance initiative, Skynet 5 is providing military satellite communications services to all three services of the UK Armed Forces, with new satellites due for launch in 2006 and 2007.

For the first contract, EMS will supply the low-noise-amplifier (LNA) assembly for the front end of the SHF Repeaters Subsystem. EMS has used its ferrite technology to include redundant LNA capability in this vital assembly, which protects the satellite from terrestrial threats while giving it the ability to establish and maintain reliable communication links from space. For the second contract, EMS will provide a solid-state, MMIC-based switch matrix, which is smaller, lighter, and more reliable than the more traditional mechanical switch-based networks. This switch matrix will route input signals to the selected output downlink, ensuring the proper routing of RF signals.

TRAK Microwave Corp.—Was awarded a Federal Supply Schedule contract from the US General Services Administration (GSA) on their GPS Time & Frequency Systems product line. The GSA contract, number GS-07F-5546P became effective on January 15, 2004 under special Item number 602-7, Time and Frequency Standards and Calibration Instruments solicitation number FCGS-W8-98-0316-N.

Products covered under TRAK's GSA contract include precise synchronization, code generation, timekeeping, clocks, Signal-Code-Frequency distribution, ands Selective Availability Anti-Spoof Modules (SAASM).

ECI Telecom—Announced that SK Group, Korea's third-largest conglomerate and one of the leading business organizations in Asia, has deployed ECI's XDM® MultiService Provisioning Platform (MSPP) equipment in a multimillion-dollar project to advance its existing network in preparation for 3G. SK Group is utilizing the XDM to bridge the gap between its legacy and next-generation infrastructure, opening up the network for the international delivery of innovative 3G services.

FRESH STARTS

Analog Devices, Inc. and TCL Mobile Communication Co. Ltd.—Announced the establishment of a joint development laboratory dedicated to the design of wireless handsets based on the 2G, 2.5G, EDGE, and 3G standards.

Anritsu Co. and Electro Rent Corp.—Have expanded their successful partnership to include Anritsu's Scorpion family of Vector Network Measurement Systems (VNMS). With the agreement, Electro Rent can now rent or lease Anritsu's MS462x series to its customers. Electro Rent already offers Anritsu's signal generators, power meters, spectrum analyzers, optical spectrum analyzers, BER testers, STM/SONET analyzers, and Site Master™ cable and antenna analyzers.

K&L Microwave—Announced that it has recently joined the WiMAX Forum as a regular member. The IEEE802.16 WiMAX standards offer extreme spectral efficiency of up to 70 MBPS of data throughput in a 15-MHz channel bandwidth (5 b/Hz) for fixed and mobile BWA requirements. Specific WiMAX protocols are optimized for fixed (IEEE802.16a) Fixed Line of Sight applications at operating frequencies greater than 6 GHz, and mobile (IEEE802.16e) vehicular/portable applications at operating frequencies less than 6 GHz.

QUALCOMM, Inc.—Announced that its board of directors has approved a 43-percent increase in QUALCOMM's quarterly cash dividend from $0.07 to $0.10 per share of common stock. The new dividend rate will be effective for the quarterly dividend payable on June 25, 2004 to stockholders of record at the close of business on May 28, 2004. This dividend increase raises the annual dividend rate to $0.40 per share of common stock.

VeriWave, Inc.—Has closed its first institutional round of funding from lead investor U.S. Venture Partners and joined by TL Ventures to address the need for 802.11 wireless LAN testing.

VeriWave was founded by a team of technology experts in networking protocols, verification, and test. The core team came from the Portland office of PMC-Sierra, Inc., a networking semiconductor company.

Heading up VeriWave are Christopher DeMonico, CEO, and Dr. Thomas Alexander, chief technology officer. MRF

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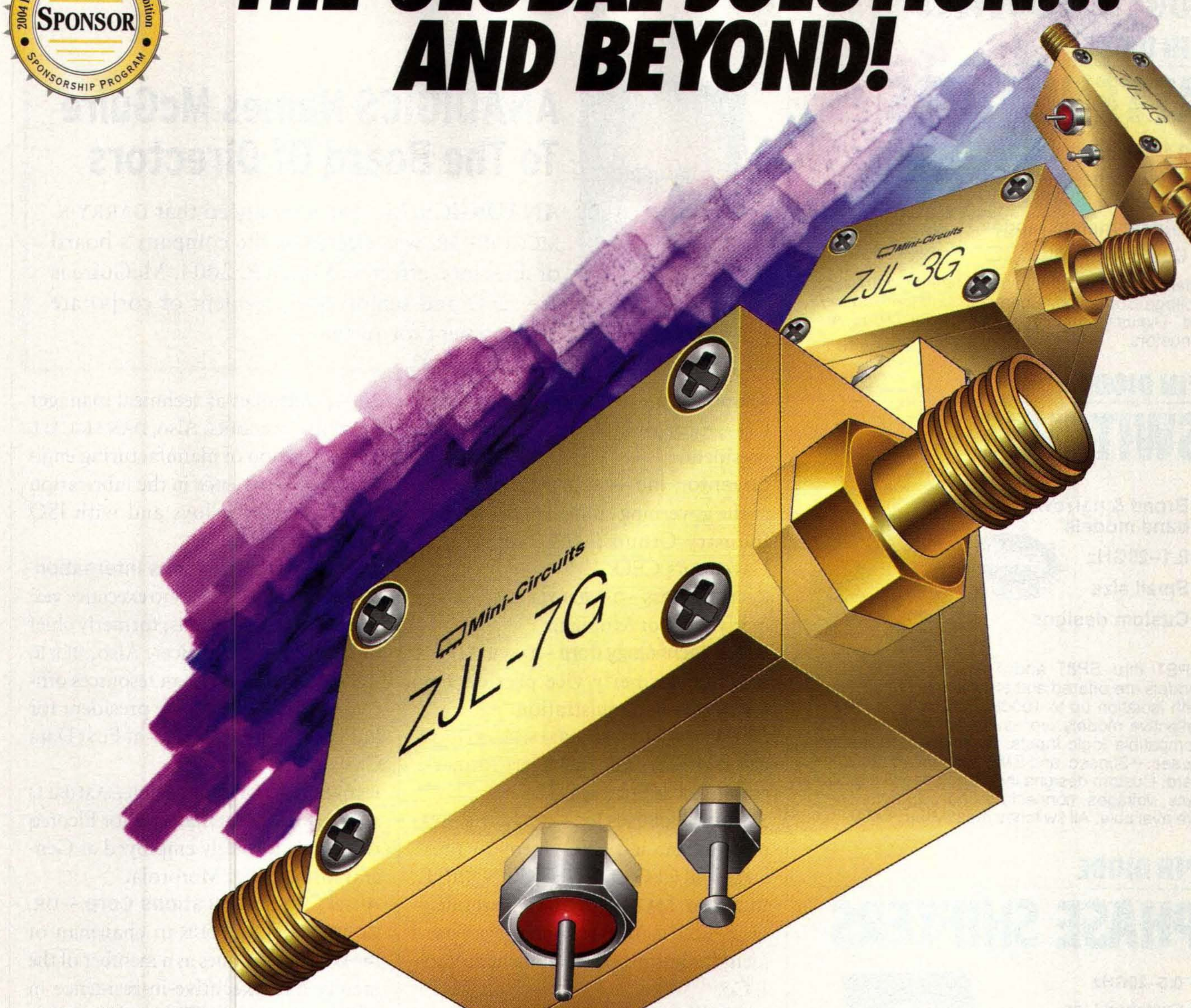

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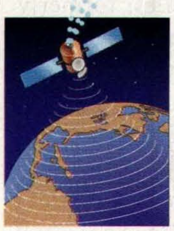

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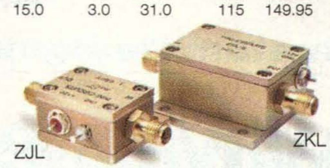
SPECIFICATIONS

Model	Freq (MHz)	Gain (typ) Midband (dB)	Gain (typ) Flat (±dB)	Max. P_{out}[1] (dBm)	Dynamic Range (Typ @2GHz[2]) NF(dB)	Dynamic Range (Typ @2GHz[2]) IP3(dBm)	I(mA)[3]	Price $ea. (1-9)
ZJL-5G	20-5000	9.0	±0.55	15.0	8.5	32.0	80	129.95
ZJL-7G	20-7000	10.0	±1.0	8.0	5.0	24.0	50	99.95
ZJL-4G	20-4000	12.4	±0.25	13.5	5.5	30.5	75	129.95
ZJL-6G	20-6000	13.0	±1.6	9.0	4.5	24.0	50	114.95
ZJL-4HG	20-4000	17.0	±1.5	15.0	4.5	30.5	75	129.95
ZJL-3G	20-3000	19.0	±2.2	8.0	3.8	22.0	45	114.95
ZKL-2R7	10-2700	24.0	±0.7	13.0	5.0	30.0	120	149.95
ZKL-2R5	10-2500	30.0	±1.5	15.0	5.0	31.0	120	149.95
ZKL-2	10-2000	33.5	±1.0	15.0	4.0	31.0	120	149.95
ZKL-1R5	10-1500	40.0	±1.2	15.0	3.0	31.0	115	149.95

NOTES:
1. Typical at 1dB compression.
2. ZKL dynamic range specified at 1GHz.
3. All units at 12V DC.



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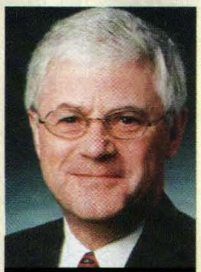


MCGUIRE

ANADIGICS Names McGuire To The Board Of Directors

ANADIGICS, Inc. has announced that GARRY K. MCGUIRE SR. was elected to the company's board of directors, effective March 9, 2004. McGuire is the CFO and senior vice president of corporate development for Avaya.

Ansoft Corp.—THOMAS A.N. MILLER to CFO; formerly served as executive vice president.

Coventor, Inc.—MIKE JAMIOLKOWSKI to the governing council of the MEMS Industry Group (MIG); remains as Coventor's CEO.

Zyray Wireless—DAVID LYLE to CFO; formerly CFO of Mobilian.

Leitch Technology Corp.—DAVID TOEWS to CFO; formerly vice president of finance and administration.

SV Microwave, Inc.—JIM SHEA to Eastern regional sales manager; formerly employed at Dynawave.

Sierra Monolithics Inc.—PETER O. CLARK to president and CEO; formerly president and CEO of LIGHTCONNECT, Inc. Also, MATT POPE to vice president of sales and marketing; formerly vice president for business development at Vari-L Co.

SyntheSys Research, Inc.—DR. LUTZ P. HENCKELS to director and CEO; formerly president and CEO of LeCroy Corp.

Applied Innovation, Inc.—MICHAEL P. KEEGAN to executive vice president and COO; formerly vice president, COO, and treasurer. Also, ANDREW J. DOSCH to vice president, CFO, and treasurer; formerly controller

2Wire—KAREN EDWARDS to the board of directors; formerly vice president of marketing at Yahoo!, Inc.

iVoice, Inc.—FRANK ESSER to the board of directors; remains as vice president of Beacon Consulting Associates.

Bomar Interconnect Products, Inc.—JOE NOONAN to national sales manager; formerly national accounts specialist.

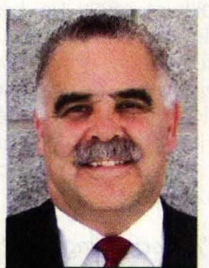
Indium Corp.—RICH BROOKS to president of the Dallas, TX SMTA chapter for 2004; continues as technical manager for global accounts. Also, DAN MCCALL to the position of manufacturing engineer; has experience in the fabrication of non-ferrous alloys and with ISO quality systems.

Qwest Communications International, Inc.—BARRY K. ALLEN to executive vice president of operations; formerly chief human resources officer. Also, JILL R. SANFORD to chief human resources officer; formerly senior vice president for human resources services at First Data Corp.

Elcoteq Network Corp.—WILLIAM (BILL) MORIN to account manager for Elcoteq Americas; formerly employed at General Instruments/Motorola.

Airnet Communications Corp.—DR. GEORGE M. CALHOUN to chairman of the board; continues as a member of the faculty and executive-in-residence in the Howe School of Technology Management at Stevens Institute of Technology in Hoboken, NJ.

Semflex—DOUG HARTJE to the position of vice president of sales; formerly served as vice president of sales and marketing for Dynawave.



HARTJE

MCGRATH

Link Microtek—BRUCE MCGRATH to senior sales engineer; formerly sales engineer for southwestern England. MRF

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CMOS Fuels 40-GHz Frequency Divider

FREQUENCY DIVIDERS play an important role in wire-line- and wireless-communications systems. Since broadband communications systems are pushing to frequencies of 40 and 60 GHz and higher, device developers must create higher-frequency dividers in support of these systems. With that in mind, Jri Lee and Behzad Razavi of the University of California at Los Angeles developed a 40-GHz frequency divider based on standard silicon CMOS technology. Configured as two cascaded divide-by-two stages, the circuit operates at an input frequency of 40 GHz and input bandwidth of 2.3 GHz while consuming 31 mW from a +2.5-VDC supply. The design has resonant tanks at both the ouptut and internal nodes of a Gilbert cell, in a classic Miller configuration in which input signals are mixed with output signals and lowpass filtered. The divider exhibits phase noise of about –115 dBc/Hz offset 1 MHz from the carrier on a die size of 0.5 ×0.7 mm. See "A 40-GHz Frequency Divider in 0.18-μm CMOS technology," *IEEE Journal of Solid-State Circuits*, April 2004, Vol. 39, No. 4, p. 594.

Active Array Receives Mobile Television

UNTETHERED TELEVISON is a reality envisioned by researcher Oded Bendov who describes an active antenna array that can be concealed within a television. The switched array supports 6-MHz video channels with low noise figure. It is basically a configuration of two L-shaped antennas spaced at least one-quarter wavelength apart and feeding wideband low-noise amplifiers (WLNAs). The noise figure of the integrated unit is optimized for all channels. See "Smart, Active, and Concealable Antenna Array for Portable Television Reception," *IEEE Transactions on Broadcasting,* March 2004, Vol. 50, No. 1, p. 71.

CMOS and DETs Lead To 5-GHz, +21.5-dBm Switches

RAPID GROWTH IN WIRELESS NETWORKS at 2.4 and 5.0 GHz has motivated several firms to develop low-cost switching solutions. One of the companies interest in this area is Mitsubishi Electric Corp., where Takahiro Ohnakado and a team of researchers developed a 5-GHz transmit/receive switch based on silicon CMOS technology. The low-cost device is capable of handling +21.5-dBm power at 5 GHz with low insertion loss (only about 0.8 dB at 5 GHz) and high isolation.

Numerous computer-aided-engineering (CAE) software simulations were performed using the Advanced Design System (ADS) suite of tools from Agilent Technologies (Santa Rosa, CA). The software was used to study the behavior of the depletion-layer-extended transistors (DETs) and their handling of different input power levels. The DETs and conventional transistors were used in the fabrication of single-pole, double-throw transmit-receive switches. A device under test (DUT) was mounted on the metal plate of a test fixture and the on-chip ground was connected to the off-chip ground of the metal plate by bond wires. Measurements were performed on stack-type switches compared to non-stack-type switches with DETs as well as with conventional transistors, and the DET/stacked-switch combination yielded the best power-handling capabilities. See "21.5-dBm Power-Handling 5-GHz Transmit/Receive CMOS Switch Realized by Voltage Division Effect of Stacked Transistor Configuration With Depletion-Layer-Extended Transistors (DETs)," *IEEE Journal of Solid-State Circuits*, April 2004, Vol. 39, No. 4, p. 577.

CMOS Gives Rise To Low-Power Bluetooth Transceiver

BLUETOOTH HAS GAINED in popularity as the price of chip sets has decreased. As low-cost technologies such as silicon CMOS are increasingly used for the RF portion of Bluetooth, that trend will continue, evidenced by the work of Sangjin Byun and associates from the Korea Advanced Institute of Science and Technology. Their efforts led to the development of a low-power CMOS Bluetooth transceiver on 0.18-μm CMOS. The chip consumes only 33 mA in receive mode and 25 mA in transmit mode when operating from a +3-VDC supply. The transmitter employs a ROM-based Gaussian lowpass filter and in-phase/quadrature (I/Q) direct-digital frequency synthesizer to minimize power consumption. The chip features a delay-locked-loop (DLL) Gaussian frequency-shift-keying (GFSK) demodulator with digital offset canceller. See "A Low-Power CMOS Bluetooth RF Transceiver With a Digital Offset Canceling DLL-Based GFSK Demodulator," *IEEE Journal of Solid-State CircuitsTransactions on Instrumentation and Measurement,* October 2003, Vol. 38, No. 10, p. 1609.

DESIGN

Understanding Terrestrial Multipath Fading Phenomena

Multipath signal fading can take on a variety of forms; by knowing its nature, it is possible to develop equalization and modulation approaches to minimize loss of transmitted information.

Signal-fading phenomena can drastically affect the performance of a terrestrial communications system. Often caused by multipath conditions, fading can degrade the bit-error-rate (BER) performance of a digital communications system, resulting in lost data or dropped calls in a cellular system. A key to preventing loss of radio performance is to understand the nature of multipath fading phenomena in terrestrial communications systems and how to anticipate when such phenomena may be a concern.

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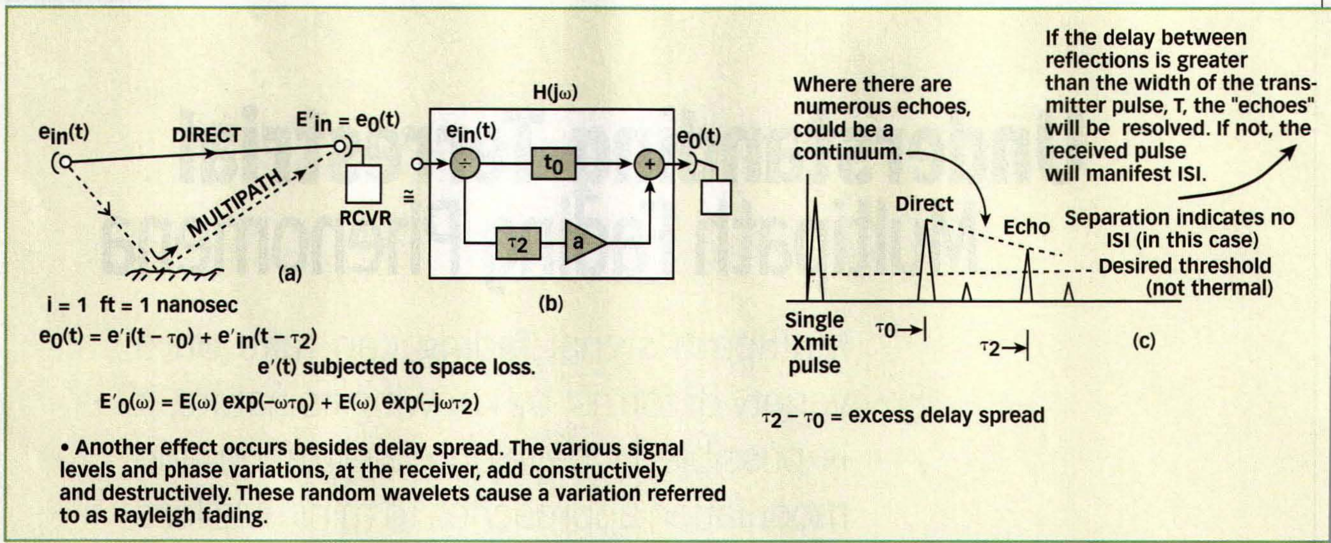
Fading can occur in many forms, including a phenomenon called flat fading. In flat fading, the same degree of fading takes place for all of the frequency components transmitted through a radio channel and within the channel bandwidth. That is, all the frequency components of the transmitted signal rise and fall in unison.

In contrast, frequency-selective fading causes different frequencies of an input signal to be attenuated and phase shifted differently in a channel. Frequently, channels experiencing frequency-selective fading may require an equalizer to achieve the desired performance. Frequency-selective fading gives rise to notches in the frequency response of the channel. Equalization techniques attempt to restore the memory less (flat fading) nature of the channels. With the proper equalization, it is possible to transmit at higher data rates before the onset of intersymbol interference (ISI) is apparent in the time domain.

Frequency-selective fading can be viewed in the frequency domain, although in the time domain, it is called multipath delay spread. The simplest measure of multipath is the overall time span of path delays from the first pulse to arrive at the receiver (the bona fide direct signal) to the last pulse to arrive at the receiver (the multipath echo). This applies to a particular threshold (not thermal) above which the last echo is significant **(Fig. 1)**. This spread has also been referred to as the excess delay spread. The two parameters most often used as statistical designators of the multipath channels are the average time delay and the delay spread. The first moment of the time-delay profile is the mean delay, and the square root of its central moment (about the mean) is defined as the delay spread. The delay spread of different systems may be comparable, but the activity of signal components (the number of echoes and their amplitudes) may be much different. The first moment of a delay spread is:



1. Multipath fading can be shown as a direct signal and a delayed signal arriving at a receiver (a), with multipath signals modeled as a delayed "bounce" path (b). When the delays between echoes are shorter than the width of the desired pulse at the receiver, transmitted symbols will collide, resulting in ISI (c).

$$\bar{\tau} = \int_0^\infty \tau p(\tau) d\tau \qquad (1)$$

and the second central moment (variance) is given as:

$$\tau = \int_0^\infty (\tau - \tau)^2 p(\tau)\, d(\tau) \qquad (2)$$

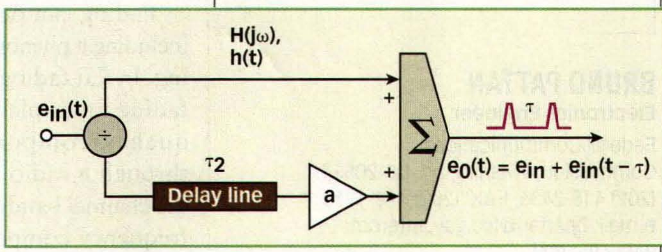
$$\tau = \bar{\tau^2} - (\bar{\tau})^2 \qquad (3)$$

Therefore, the root-mean-square (RMS) delay spread is:

SEE EQ. 4 IN BOX ON P. 65

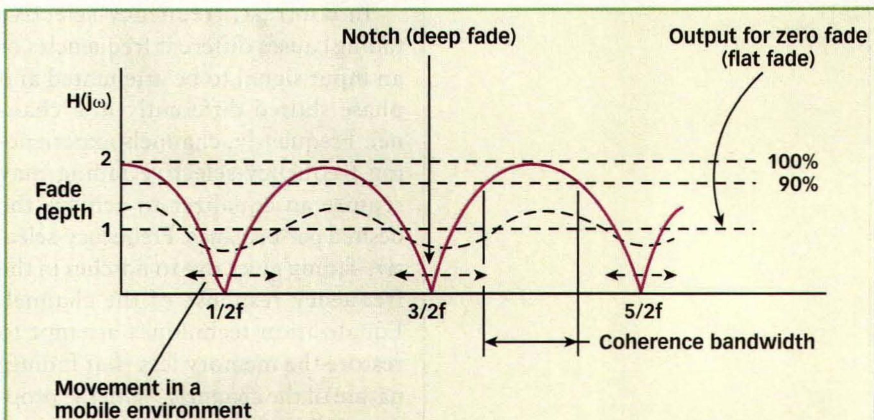
Figure 1a offers a simple example of delay spread. It shows the pulse for the direct path and for the indirect path (multipath). The first pulse arrives at τ_o after the transmitted pulse and the echo at τ_2. The difference in time is the excess delay spread. In an actual system, there are multiple paths and in the interval of the delay spread there is a raft of echo pulses, and not just two discrete paths as shown in the figure. This may also be a continuum and may not be uniform, but more concentrated near τ_o, and falling off in amplitude as the signals travel further in time. Of course, it is possible that some farther-out pulses may be bigger than the original pulse caused, for example, by specular reflections (forward scatter).

Frequency fading due to time dispersion is also known as ISI. Delay spread in time causes ISI, in which there is time dispersion of the signal. The time dispersion sets a limit on the speed at which modulated symbols can be transmitted in the channel. Because of the dispersion, symbols can collide and result in distorted output data. In this type of fading, the differences in delay between the various reflections arriving at the receiver can be a significant fraction of the data symbol interval, establishing conditions for overlapping symbols.



2. This delay-line canceller can be used.

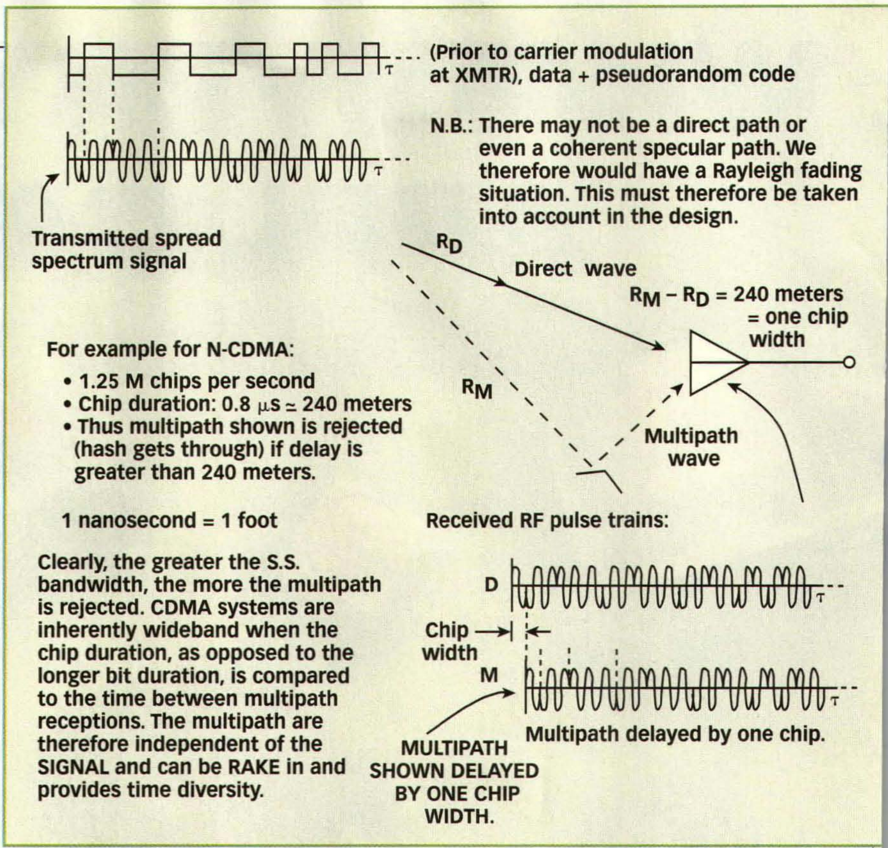
If the time-delay spread equals zero, there is no selective fading. As a rule of thumb, a channel can be considered flat when τ_{rms}/T is less than 0.1 where T is the symbol period. Statistical analysis can determine the range of frequencies over which a channel can be considered flat—that is, all received signal levels are approximately comparable in magnitude and the phases



3. This plot shows the amplitude response of a frequency-selective fading channel.

are approximately in unison (do not negate each other). Using the statistical approach, the coherence bandwidth is defined as the bandwidth over which the fading statistics are correlated to better than 90 percent **(Fig. 2)**. Clearly, if two frequencies do not fall within the coherence bandwidth, they will fade independently.

Consider the multipath model depicted in Fig. 1b. It shows a single reflector of the transmitted signal. A pulse is propagated toward the receiver via a direct path and a single bounce path. The figure portrays simple conditions; in fact, the echoes are numerous. The delay is indicated by τ_2 relative to the direct path where τ_o is assumed to be the epoch point. Clearly, the direct path delay is shorter than the echo delay. At the receiver, the two signals are combined, with the differential delay being τ_Δ seconds in length. From signal theory, this is analogous to a delay-line



4. The effects of multipath signal distortion can be minimized through the use of spread-spectrum techniques.

canceller (Fig. 2).

An ideal delay line will produce an output signal, which is an exact replica of the input signal, but delayed in time by τ_2. A network which had the property that $e(t)_{out} = e(t)_{in} + ein(t-\tau_1)$ would have to possess $\exp(-j\omega\tau)$ as a transcendental transfer function and the delayed signal input at $t = \tau_2$ in response to a input at τ_o (epoch). The similarity to the propagation model illustrated in Fig. 1b should be apparent.

To understand the nature of signal delays for a given network, it is necessary to find the frequency-domain response (the frequency selectivity) of that network. Since the delayed pulse is assumed to fall with the direct pulse upon their arrival at the receiver, the end result will be frequency-selective fading. Mathematically, taking the Fourier transform of both sides of the system function, $H(j\omega)$, from Eq. 1:

SEE EQ. 5 IN BOX ON P. 65

If the multipath signal, a, is equal to a(t), the multipath function is time dependent, as would be prevalent for a mobile communications receiver. The system function $H(j\omega)$ is complex, but it is the amplitude (real) part that is of interest, and the frequency-domain characteristic of the network follow from analysis. Applying Euler's identity for $\exp(-j\omega\tau)$ results in:

$$H(j\omega) = 1 + a\ \exp(-j\omega\tau) = (1 + a\ \cos\ \omega\tau) - j\ a\ \sin\omega\tau$$

SEE EQ. 6 IN BOX ON P. 65

For a =1 (Eq. 3),

$$|(H(\omega))| = \sqrt{2 + 2\cos(\omega\tau)} = \sqrt{2}\sqrt{2[1 + \cos(\omega\tau)/2]} = 2|\cos(\omega\tau/2)| \quad (7)$$

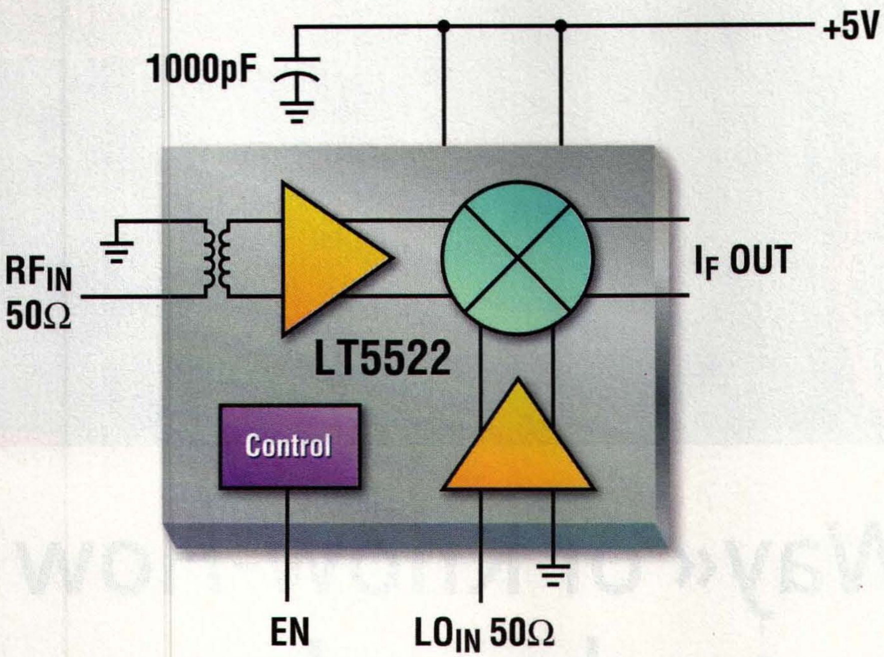
Equation 3 is the amplitude frequency response of the channel, which can be plotted as shown in **Fig. 3.** Equation 3 goes to zero ("fade notches") when the value of τ is:

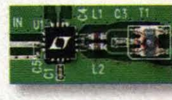
$$\tau = \pi/\omega,\ 3\pi/\omega,\ 5\pi/\omega,\ \ldots = 1/2f,\ 3/2f,\ 5/3f,\ \ldots$$

For example at a frequency of τ = 0.5f, there will be a null in the transmission, and the receiver will exhibit zero output (frequency-selective fading). Other applicable frequencies will have various degrees of fading.

Coherence bandwidth has been defined as the bandwidth over which

High Linearity, Low LO Drive





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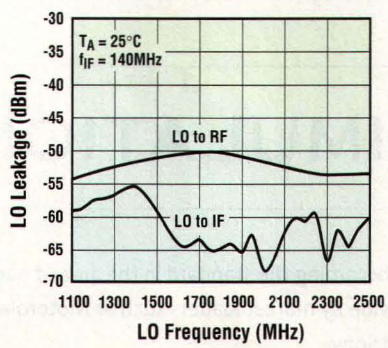
LO Leakage vs LO Frequency



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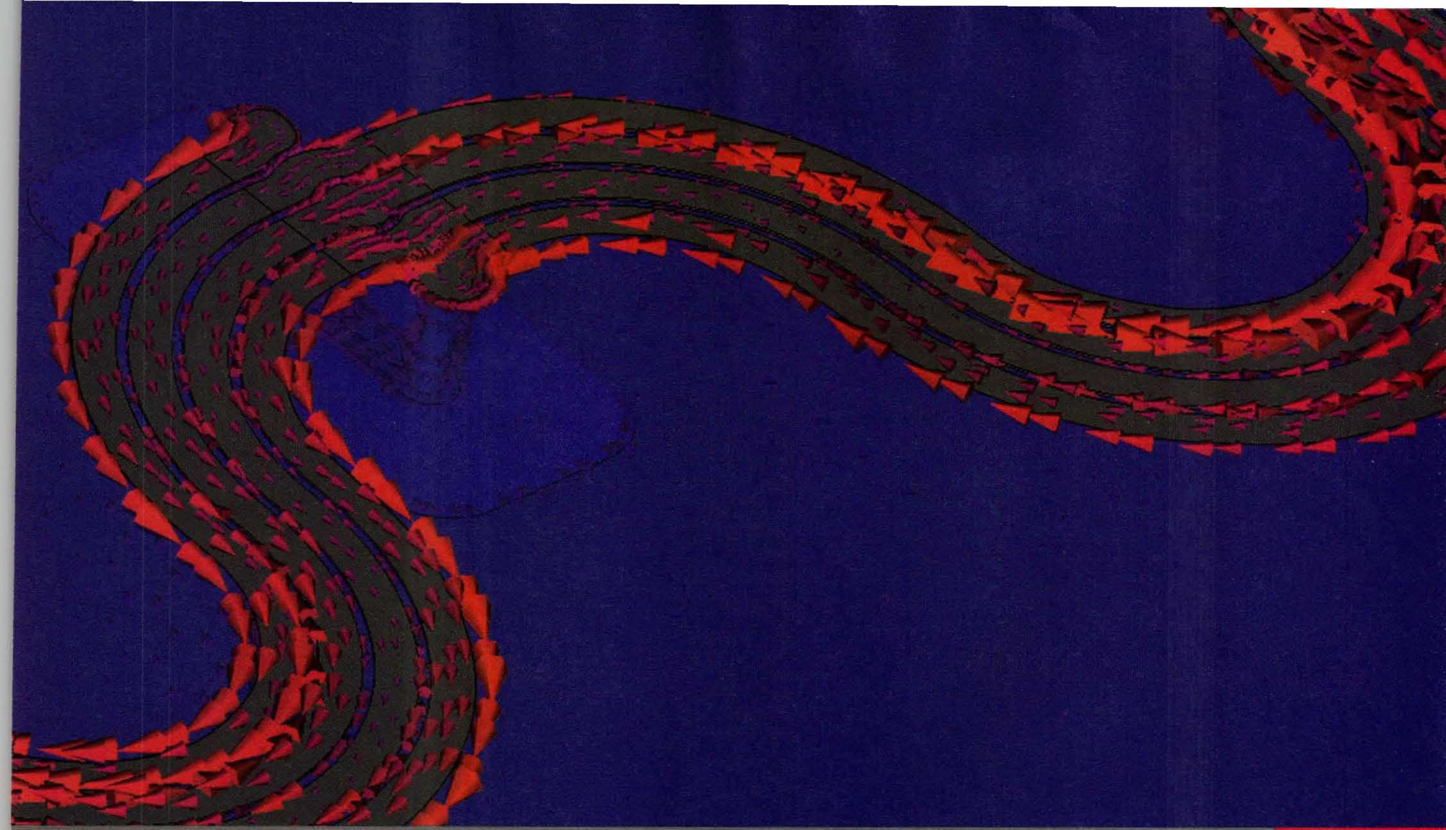

$$\tau_{rms} = \sqrt{\overline{\tau^2} - (\overline{\tau})^2}$$
$$= \sqrt{(mean\ square - square\ of\ the\ mean)} \qquad (4)$$

$$E_0(\omega) / \left(E_{in}(\omega) = H(j\omega) = 1 + a\ \exp(-j2\pi f\tau)\right) \qquad (5)$$

$$|H(\omega)| = \sqrt{(1 + a\ \cos\omega\, t)^2 + (a\ \sin\ \omega\tau)^2}$$
$$= \sqrt{(1 + a\ \cos\ \omega\, t)(1 + a\ \cos\ \omega\, t) + a^2 \sin\ \omega\tau^2}$$
$$= \sqrt{1 + a^2\ \cos\ 2\omega\, t + 2a\ \cos\ \omega t + a^2 \sin\ \omega\tau}$$
$$= \sqrt{1 + a^2 + 2a\ \cos(\omega\tau)} \qquad (6)$$

the fading statistics are correlated to better than 90 percent (Fig. 3). Going back to Eq. 3 for values of a < 1, there is no complete cancellation at the notches. The transfer output is undulatory (dotted curve in Fig. 3). As the multipath content becomes highly attenuated, the multipath approaches zero and receiver input reverts to a "flat fade" condition ($|H(\omega)|=1$). Clearly, the output is equal to the transmitted signal, but attenuated by the free-space loss.

The multipath null locations are also a function of frequency and dynamic differential delays between the direct and multipath signal components. The time τ required for a radio wave to travel a given distance d in free space is $\tau = d/c$, where c is the speed of the electromagnetic (EM) wave (in a vacuum). The delay time of the multipath signal after the arrival of the direct signal is found from the difference between the direct and multipath signal distances,

$\tau = (d_m - d_d)/c$, where τ is the differential delay.

The multipath model described here is rather simplistic since only a single discrete signal path has been considered. Under real-world conditions, a network would exhibit a multitude of discrete multipath signals and possibly even a continuum of multipath signals (Fig. 1). It should be noted that the echo signals need not be smaller than the direct signal wave. If the difference in path length is large, the fading characteristics will vary greatly even with small frequency separations.

Frequency-selectivity fading in the time domain is manifested as ISI or smearing in the time domain. Multipath is not always a bad thing, since there would be no cellular industry without it. A multiplicity of randomly reflected and diffracted signals, reaching the cellular handset, with random amplitude and uniform phase distribution, assumes Rayleigh statistics. For the rare occasion when there is a line-of-sight signal path to the base station, the statistics are Ricean in nature.

Continued on page 81

Design Finite Impulse Response Digital Filters

This four-part article series draws to a close with a practical example of designing a multipart FIR filter to meet the spectral-mask requirements of GSM cellular systems.

Wisely employing digital capabilities can result in optimum filter designs with a minimum number of bits. As was seen last month, in some cases, even having an excess amount of processing power may not result in additional filter precision. The final installment of this four-part article series will examine the use of fixed-point filtering and provide a practical example of DSP-based FIR filtering to meet the spectral mask requirements of a Global System for Mobile Communications (GSM) cellular system.

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Quantizing the coefficients correctly is not the only thing to keep in mind when implementing an FIR filter with fixed-point arithmetic. Suppose it is necessary to implement this filter using the direct-form structure. **Figure 42** shows the structure as a reference for five coefficients. For the example at hand, we have 16-b coefficients, and suppose we need to filter 16-b data that is well scaled in the [–1, 1] range. We can generate random data with that characteristic as follows:

q = quantizer([16, 15], 'RoundMode', 'round');

xq = randquant (1, 1000, 1);

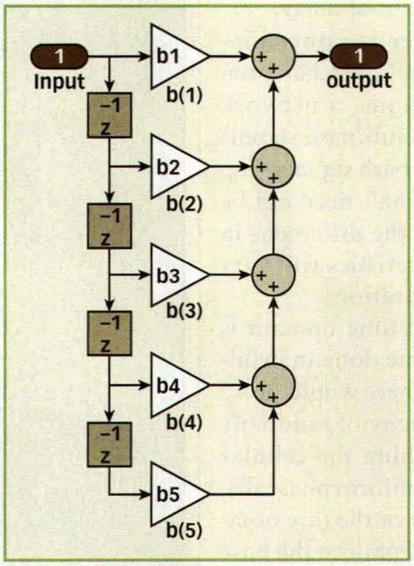
[In order to reproduce the results, the seed of the random number generator can be reset prior to generating the random vector, rand('seed', 0).] The [16, 18] format is used for the coefficients for illustration purposes. Since the input is already quantized, an input quantizer or a multiplicand quantizer is not needed:

Hq = qfilt('fir', {b}, ...
'CoefficientFormat', [16,18]);
set(Hq, 'InputFormat', 'none')
set(Hq, 'MultiplicandFormat', 'none');

For reference, the other parameters are set to default values:

OutputFormat = [16 15]
ProductFormat = [32 30]
SumFormat = [32 30]

but will be temporarily set to 'none' in order to have a reference for



42. This is a direct-form implementation of an FIR filter with five coefficients.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comparison:

set(Hq, 'OutputFormat', 'none');
set(Hq, 'ProductFormat', 'none');
set(Hq, 'SumFormat', 'none');
yi = filter(Hq, xq);

Quantity yi represents an "ideal" output or the best output one can hope to compute. Aside from using the 16-b quantized coefficients, all computations are performed with double-precision arithmetic. Quantity yi provides a nice reference signal for comparison purposes.

If the parameters are set back to their default values, it becomes apparent that the product format is not accurate for this case. The multiplication of [16, 18] coefficients with a [16, 15] input sample results in a [32, 33] product. On a DSP processor, two 16-b registers are being multiplied and the result stored in a 32-b product register. The correct setting for the ProductFormat is [32, 33]:

set(Hq, 'OutputFormat', quantizer([16, 15]));

set(Hq, 'ProductFormat', quantizer([32, 33]));

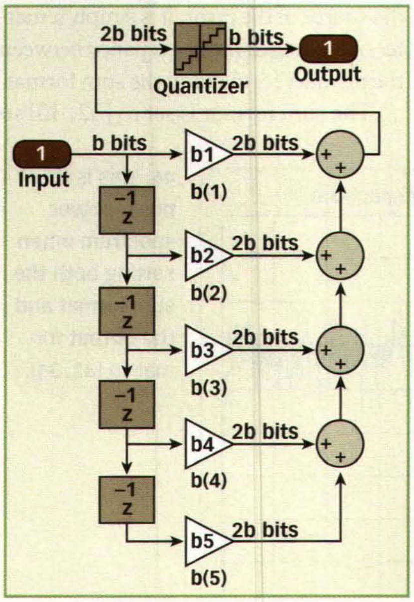
set(Hq, 'SumFormat', quantizer([32, 30]));

yq = filter(Hq, xq);

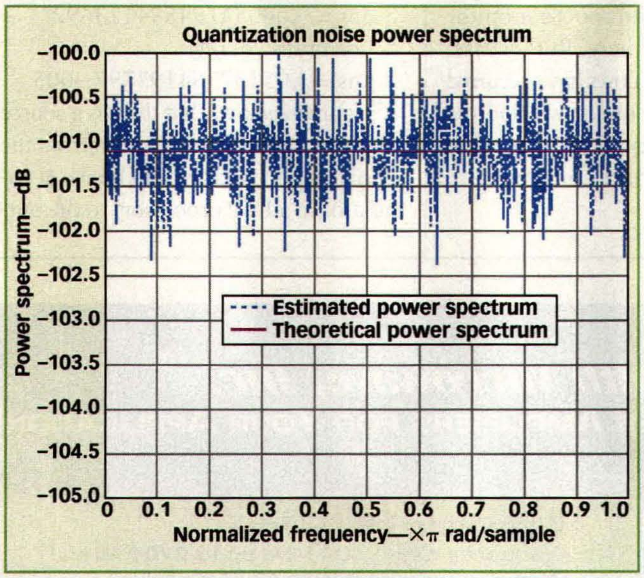
The qreport(Hq) reporting function is an extremely useful tool to monitor what has happened here. In this case, it reports that no overflows have occurred **(see table)**. To measure how good the output is, the energy of the error and the maximum error are compared:

norm(yi - yq, 2)
ans = 0.00054794884123692
norm(yi - yq, inf)
ans = 3.05137364193797e-005

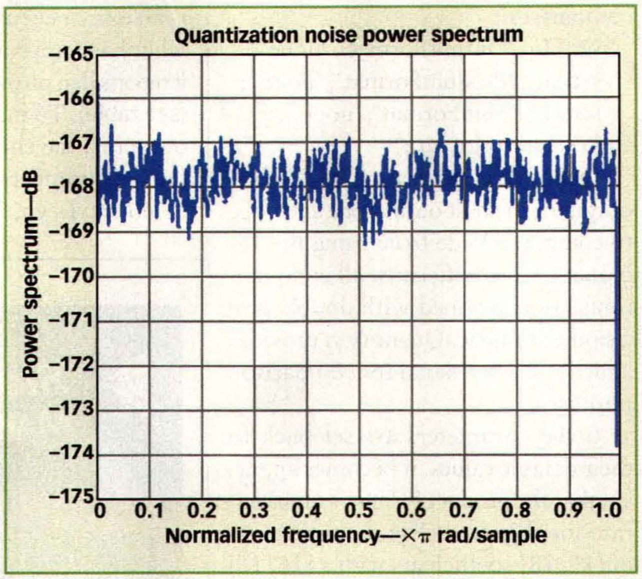
Figure 42 shows that there is a source of error when moving the data from the set of adders (what would be the accumulator in a DSP processor) to the out-



43. This FIR filter model shows the quantization noise by reducing the number of bits from the adders to the output.



44. This plot shows the theoretical and estimated power spectrum of the quantization noise.



45. This is the noise-power spectrum when making the output format equal to the sum format.

put. The word length is being reduced from 32 b to 16 b. The theoretical power spectrum of the quantization noise at the output of the filter corresponding to the model in **Fig. 43** is

$$S_y(\omega) = \left|H_n\left(e^{j\omega}\right)\right|^2 \sigma_x^{\,2}$$

where $H_n(e^{j\omega})$ is the transfer function from the noise source to the output (in this case, simply 1) and σ_x^2 is the power spectrum of the noise source (in this case, a constant and equal to the variance of the noise):

$$\sigma_x^{\,2} = 2^{2(1-b)} / 12$$

where :

b = the number of bits.

(This formula is approximate because the signal at the accumulator does not cover the entire range [– 1, 1] and because an analog signal is not being quantized. Rather, the number of bits in an already quantized signal is being reduced.) In this case, the theoretical power spectrum is constant and for 16 b is

Sy(_) = 10log10 22(–15)/12 = 101.100811159671 dB

An estimate of the noise power spectrum can be computed with the "nlm" function:

[H, w, Pnn] = nlm(Hq, 512, 100);

Figure 44 shows a plot of the "Pnn" function (in dB) compared to the theoretical power spectrum.

If the quantization noise in Fig. 43 is the only noise in the system, it should be possible to obtain an output that exactly matches yi by setting the output format to be the same as the sum format (one can think of it as the ability to "look inside the accumulator"):

set(Hq, 'OutputFormat', quantizer([32,30]));

yq = filter(Hq, xq);

norm(yi - yq, 2)

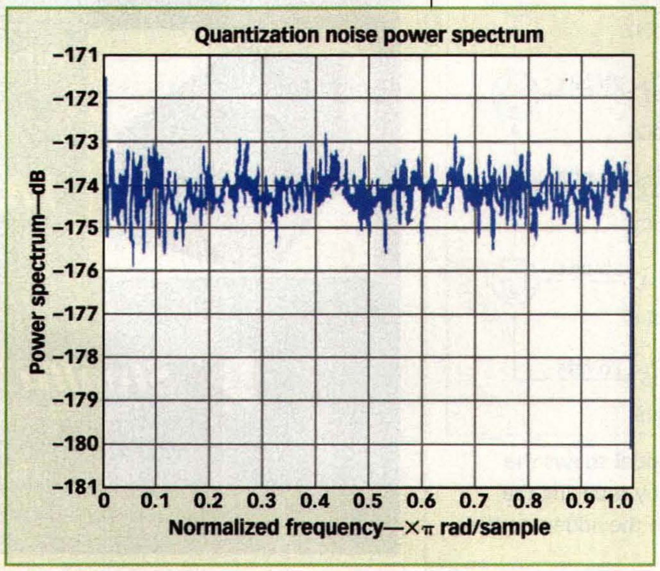
ans = 2.02838467848398e-006

norm(yi - yq, inf)

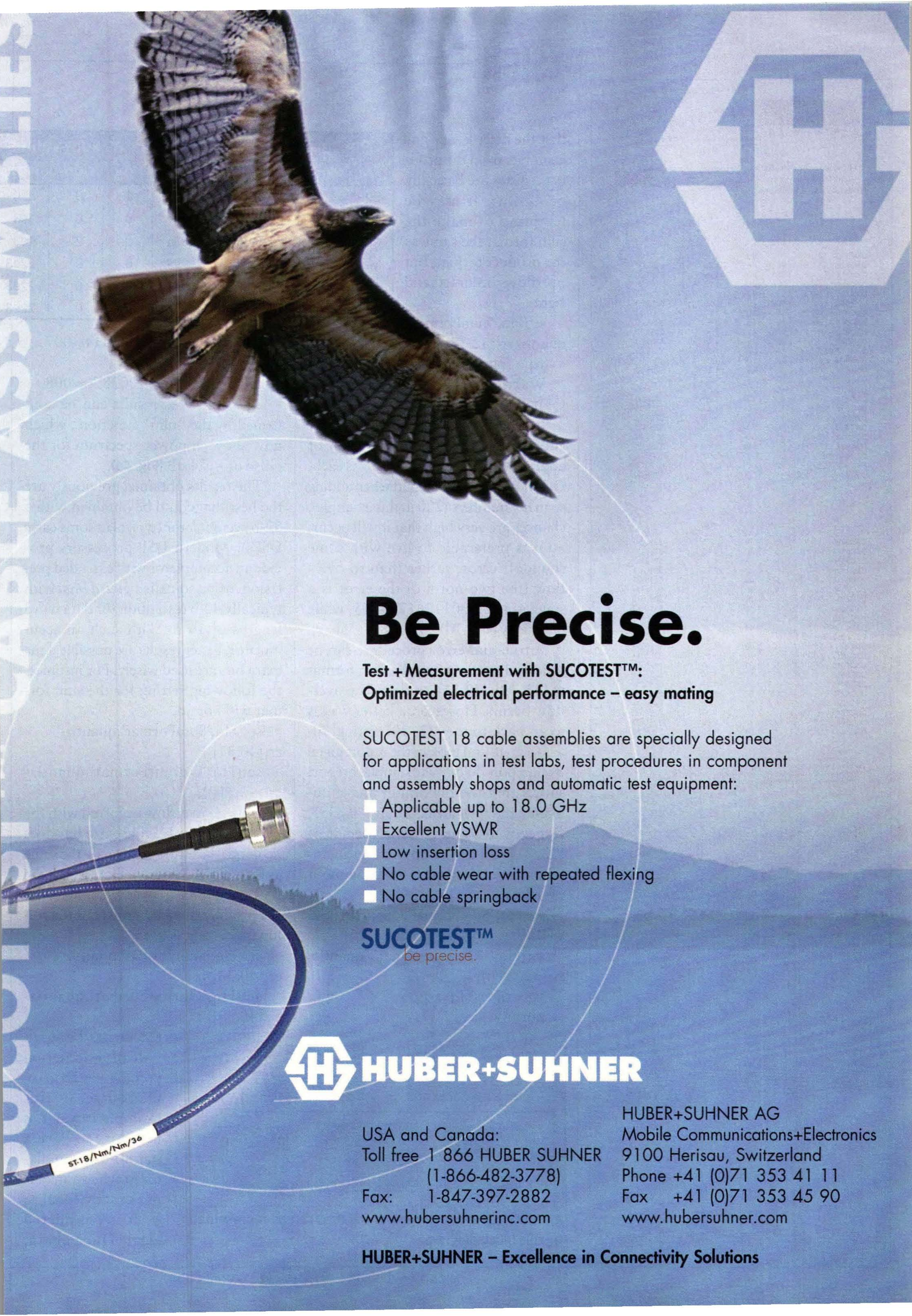
ans = 7.98609107732773e-008

While the error has clearly been reduced, there is still some left, indicating some roundoff still present in the system. This is confirmed by looking at the power spectrum for the noise using the "nlm" function. **Figure 45** shows the plot of the power spectrum. The noise is obviously less than before (about –168 dB), which is consistent with the smaller errors computed here. To find the source of the error, it is simply a matter of looking at the discrepancy between the product format and the sum format.

The sum format is set to [32, 30] so



46. This is the noise-power spectrum when setting both the sum format and the output format to [32, 31].



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that the three least significant bits from the product register are basically being lost. It may be tempting to make the sum format the same as the product format, but overflows occur left and right:

set(Hq, 'SumFormat', quantizer([32,33]));
yq = filter(Hq, xq);
Warning: 1944 overflows in QFILT/FILTER.

In general, for additions *k* bits are not enough to always store the result of adding two quantities with *k* bits each. Overflow *might* occur, and when adding so many numbers (220 in this example), chances are very high that it will occur. So it is preferable to live with some roundoff error, rather than to overflow (the two-norm of the error is a staggering 2.09011261755715, while the infinity norm is 0.285711827455089).

A trial-and-error procedure can be followed for reducing the sum format to [32, 32], [32,31], etc., until no overflow occurs. However, a better way is to go back to the [32, 30] setting, filter a signal, and look at the report given by "qreport." For this example, qreport shows that the maximum and minimum sum values are 0.527 and –0.5357, respectively. Therefore, a format of [32, 31] will be the optimal setting to minimize quantization noise without overflow:

set(Hq, 'SumFormat', quantizer([32, 31]));
set(Hq,' 'OutputFormat', quantizer([32, 31]));
yq = filter(Hq, xq);
norm(yi - yq, 2)

The "qreport" function tabulates sum values

PARAMETER	MAX	MIN	NOv	NUn	NOps
Coefficient	0.12	-0.026	0	0	220
Input	0.999	-0.999	0	0	1e3
Output	0.474	-0.536	0	2	1e3
Multiplicand	0.999	-0.999	0	0	22e3
Prod	0.12	-0.12	0	0	22e3
Sum	0.527	-0.537	0	0	22e3

ans = 7.53800283935414e-007
norm(yi - yq, inf)
ans = 2.93366611003876e-008

The improved results can be confirmed by the "nlm" function , which now shows a power spectrum for the noise of –174 dB **(Fig. 46)**.

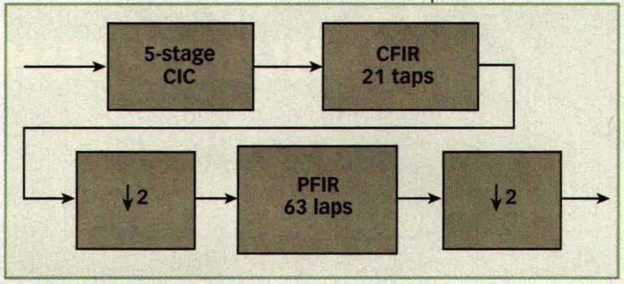
The results obtained previously are the best that could be obtained with a 32-b accumulator (typical in some early DSPs). Modern DSP processors provide an accumulator with extended precision, using so-called *guard bits*, with typically 40-b resolution for data word lengths of 16 b. With such an accumulator, better results are possible if the extra bits are used wisely. For instance, the following setting for the sum format will not do:

set(Hq,'SumFormat',quantizer([40,31]));
set(Hq,'OutputFormat',quantizer([40,31]));

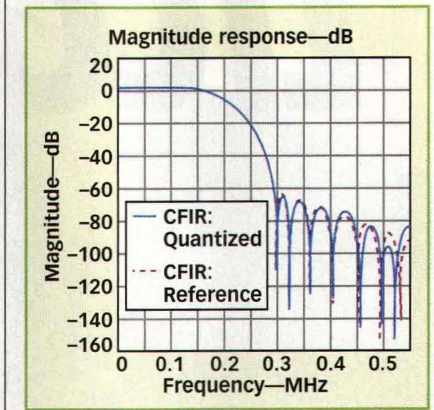
because no overflow occurred with the [32, 31] setting. Having extra bits does no good (the errors are exactly the same as for the [32, 31] case). However, if the LSB weighting is set the same as for the product format, namely, if the following setting is used:

set(Hq,'SumFormat',quantizer([40,33]));
set(Hq,'OutputFormat',quantizer([40,33]));

the errors between "ideal" and actual become exactly zero. Of course, in this example it was not necessary to have a full 40-b accumulator to achieve an output exactly equal to what is considered ideal. Once again,



47. The decimation portion of the DDC can be represented by this block diagram.



48. This is the magnitude response of the five-stage CIC decimator.

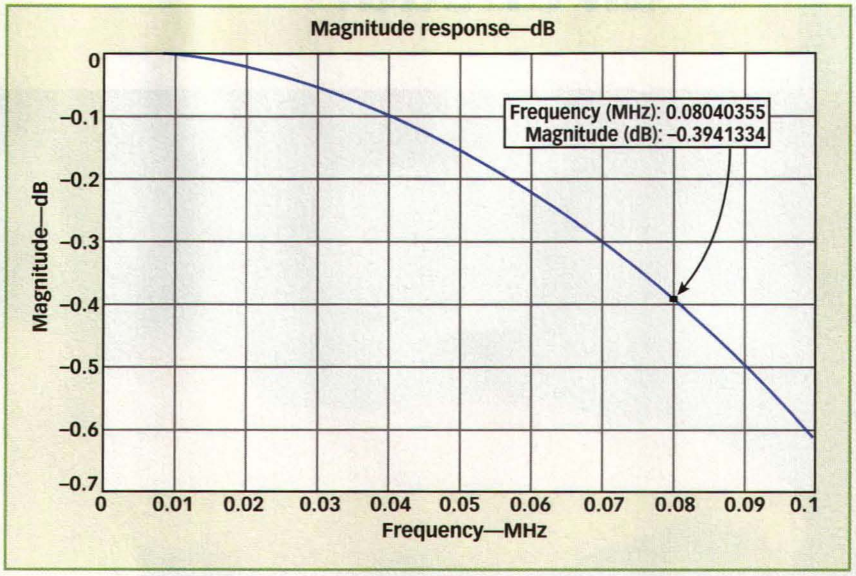
from the report generated with "qreport," it was evident that a setting of [34, 33] for both sum and output would have been sufficient.

In an actual DSP, the output is not of the same width as the accumulator, so realistically it is necessary to set the output format back to either 16 b or 32 b in this example. Assuming 32 b for the output, qreport can once again be used to determine the best possible output setting. In this case, [32, 31] is the best setting because the minimum value reported at the output is −0.5357. The two-norm and infinity-norm of the errors are:

norm(yi - yq, 2)
ans = 6.82098421980174e-009
norm(yi - yq, inf)
ans = 3.49245965480804e-010

which compare favorably with the values 7.53800283935414e-007 and 2.93366611003876e-008, respectively (which were the best that could be done for a 32-b output with a 32-b accumulator).

To show the practical benefits of FIR filter design, two FIR filters will be used for a digital downconverter (DDC) for GSM, based on a quad multistandard DDC chip (model 4016) from Graychip.[18] A DDC essentially has two parts. The first, which consists of a numerically controlled oscillator (NCO) and a mixer, translates an intermediate-frequency (IF) signal to baseband. The second part is a multistage decimator used to isolate the desired signal. This design example will focus on the sec-

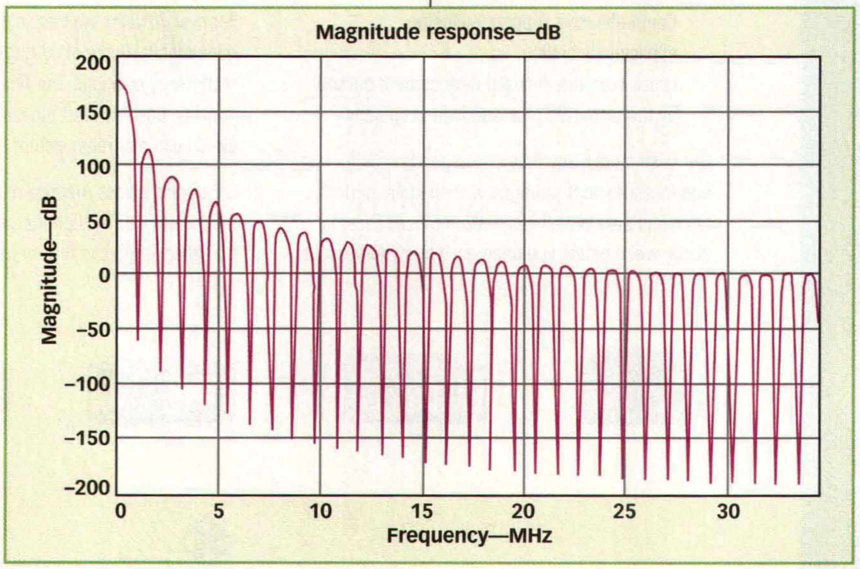


49. This plot shows the passband details of the scaled five-stage CIC decimator.

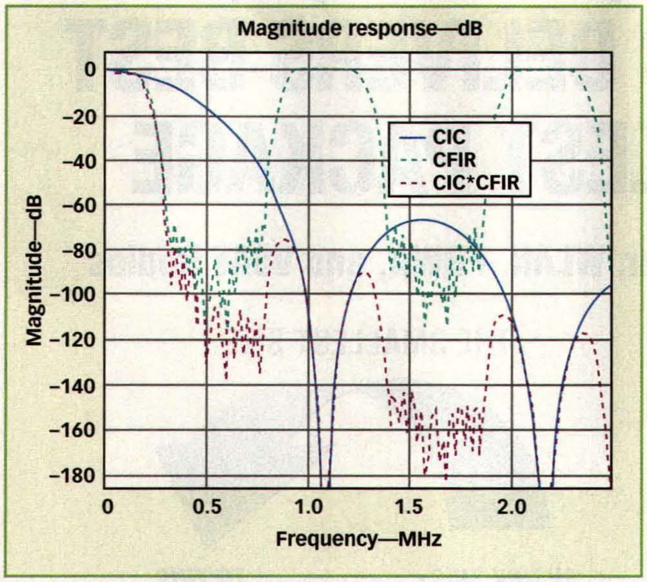
ond part.

For decimation, the 4016 provides for a multistage approach consisting of three FIR filters. Of the three filters, one is a cascaded integrator-comb (CIC) five-stage decimator **(Fig. 47)** and two are programmable decimate-by-two FIR filters. The five-stage CIC filter takes the high-rate input signal and decimates it by a programmable factor. The CIC filter is followed by a 21-tap compensation FIR (CFIR) filter that equalizes the "droop" due to the CIC filter and provides further lowpass filtering and decimation by two. The CFIR is followed by a 63-tap programmable FIR (PFIR) filter that provides a final decimation by two.

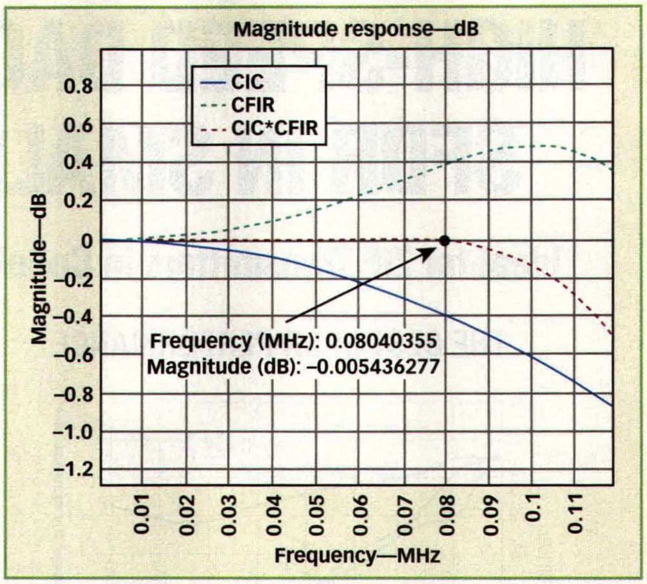
In a multistage decimator, the simplest (highest-rate) filter appears first, with the complexity of the filters increasing in the subsequent stages. In the 4016, the CIC filter operates without multipliers, providing (coarse) lowpass filtering using adders and delays. Its less-than-ideal magnitude response exhibits passband droop that progressively attenuates in-band signals. The relatively simple CFIR filter (only 21 taps) is designed primarily to compensate for the CIC's droop. The PFIR filter is the most complex, with 63 multiplica-



50. This plot shows the magnitude response of the CFIR filter.



51. The magnitude response of the CIC filter is overlaid with the response of the CFIR filter, as well as the combined response of the two.



52. The passband details of the CIC filter is overlaid with the response of the CFIR filter, as well as the combined response of the two.

tions per sample, and thus operates at the lowest rate. This is an example of a design using fixed filter order. The CFIR and PFIR are linear-phase filters, with 16-b available word length for their coefficients.

The programmable 4016 is designed for use with different communications standards. For this reason, the decimation factor of the CIC filter can be selected as well as the coefficients for both the CFIR and PFIR filters. For GSM, the following requirements apply:

input sample rate of 69.333248 MHz

CIC decimation factor of 64

CFIR input sample rate of 1.083332 MHz

PFIR input sample rate of 541.666 kHz

PFIR ouptut sample rate of 270.833 kHz

passband width of 80 kHz

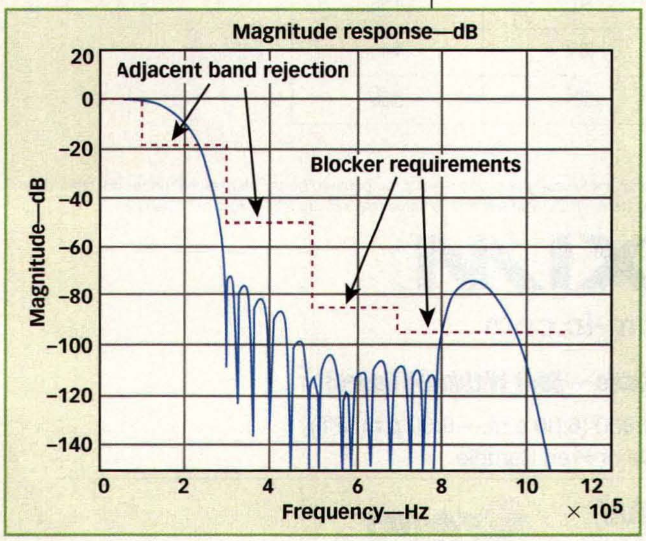
passband ripply of less than 0.1 dB peak to peak.

The CIC filter has five stages and a decimation factor of 64. Its magnitude can be shown **(Fig. 48)** by creating a CIC decimation object and using the "fvtool" function:

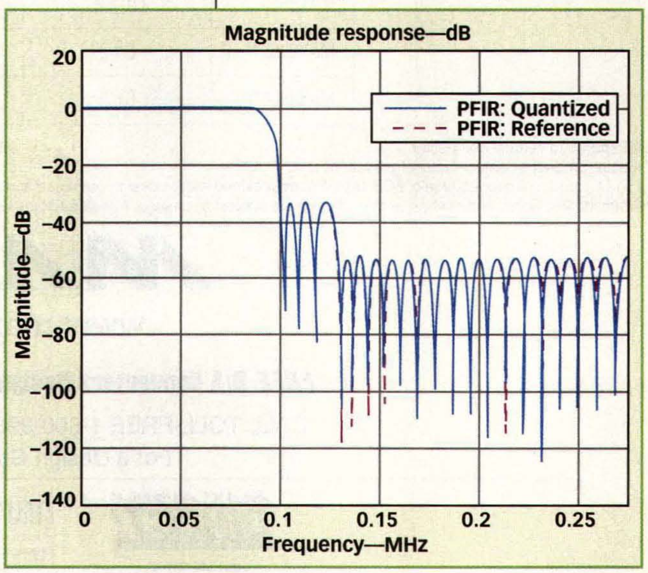
Hcic = mfilt.cicdecun(64, 1, 5);
fvtool(Hcic)

The filter exhibits a $[\sin(x)x]^5$ shape. To compensate for the large DC gain (more than 180 dB), the 4016 provides a power-of-two scaling prior to data entering the filter, in order to avoid overflows. Passband details are shown in **Fig. 49**, with a droop in magnitude response of about 0.4 dB at 80 kHz, or much more than the GSM target specifications.

To improve on this performance,



53. The magnitude responses of the CIC and CFIR filters are compared to the GSM spectral mask requirements.



54. This plot shows the magnitude response of the PFIR filter.

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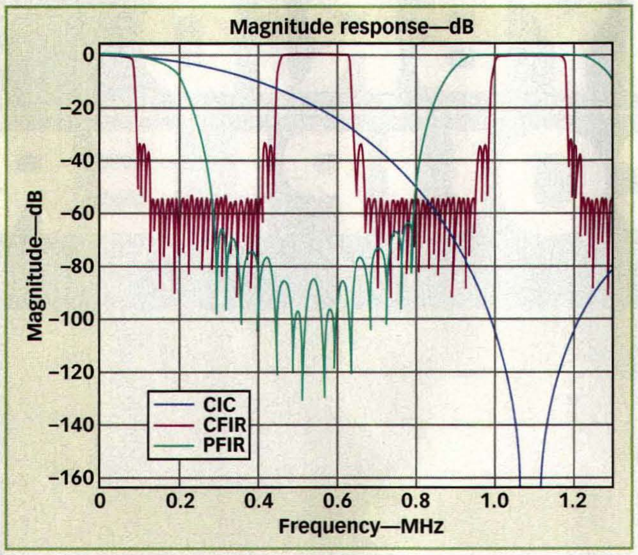
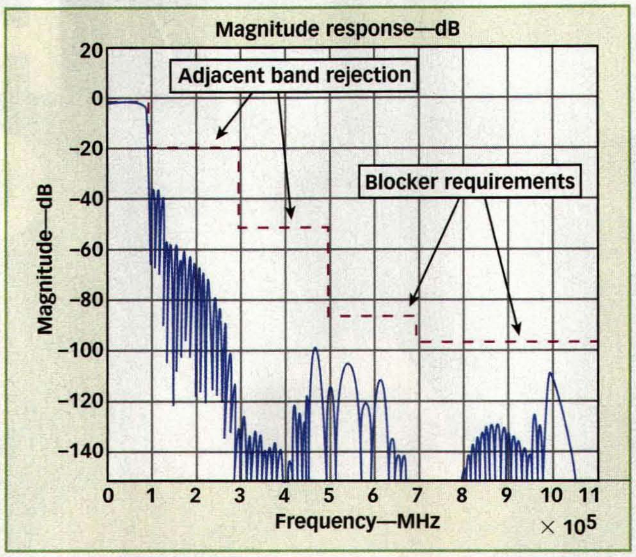


55. This plot shows the magnitude responses of the CIC, CFIR, and PFIR filters.



56. The combined responses of the CIC, CFIR, and PFIR filters is compared with the GSM spectral mask requirements.

the "firceqrip" function was chosen for several reasons. It allows for compensation of responses having the form $|\sin(x)/x|^N$. It also permits the filter order to be specified, and allows for a slope in the stopband, which can be used to attenuate spectral replicas of the PFIR filter that follows. The function also makes it possible to constrain peak passband and stopband ripples, and allows passband-edge frequency (rather than the cutoff frequency) to be specified. For this example, since the passband is the interval [0, 80 kHz], it is desirable to compensate for the CIC droop in the passband only.

The filter order is determined by the hardware. For the passband-edge frequency, 80 kHz is selected since it is the final passband of interest. Very small passband ripple is chosen (0.01 dB) in order for the overall ripple to be within specification, keeping in mind that there is still the PFIR filter to follow which will add its own passband ripple. The stopband attenuation is selected as 40 dB with a 60-dB slope to provide adequate attenuation of the PFIR spectral replicas. Because this is a five-stage CIC, the droop is of the form $|\sin(x)/x|^N$ so 5 is selected as the sinc power for which to compensate. Finally, the sinc frequency factor is chosen as 0.5.

Figure 53 shows an overlay of the GSM spectral mask requirements[18] with the combined response of the CIC filter and the CFIR filter. It is evident from the plot that the contribution of these two filters is not sufficient to meet the GSM requirements for either adjacent-band rejection or blocker requirements. The combined filter still has a transition band that is too large, due to the large transition band from the CFIR filter.

The PFIR filter is intended to be used to do the extra work required to meet the GSM specifications. It is a linear-phase FIR filter consisting of 63 taps, but not trivial. If a simple lowpass filter is designed with the "remez" or "gremez" functions:

```
N = 62;
Fs = 541666;
F = [0 80e3 100e3 541666/2]/(Fs/2);
A = [1 1 0 0];
W = [1 1];
pfir = gremez(N, F, A, W);
Hpfir = mfilt.firdecim(2, pfir);
```

the passband ripple requirement will not be met. The weighs can be altered to get better passband ripple, but the adjacent-band specifications can't be violated in the process. A setting of W = [10, 1]; would do the trick, but with significantly less adjacent-band attenuation. A compromise can be achieved by setting up the design as a lowpass filter with two separate stopband regions, each with a different weight used in the optimization:

```
N = 62;
Fs = 541666;
F = [0 80e3 100e3 122e3 132e3 541666/2]/(Fs/2);
A = [1 1 0 0 0 0];
W = [10 1 10];
pfir = gremez(N, F, A, W);
Hpfir = mfilt.firdecim(2, pfir);
```

Figure 54 shows the quantized PFIR filter. The maximum coefficient is 0.3378, so the [16, 16] format is used again. The reference (non-quantized) filter is also shown, but it is practically indistinguishable from the quantized response. The different attenuation in the two stopbands is due to the different weighting. The passband ripple is kept small in order to not exceed the allowable peak-to-peak specification.

Figure 55 shows the magnitude responses of all three (CIC, CFIR, and PFIR) filters while **Fig. 56** shows the overall response of the combination. As the combination response shows, the GSM spectral mask requirements are easily met. The peak-to-peak ripple requirement of 0.1 dB is easily met. The design could be further tuned to provide a smaller transition width at the expense of larger peak-to-peak ripple and/or less adjacent-band rejection. MRF

REFERENCE

18. Graychip, Inc., "GC4016 Multistandard Quad DDC Chip Data Sheet," Revision 1.0, August 27, 2001.

Continued from page 65

Combating time-dependent fading in a dynamic channel could be daunting. One solution is the use of adaptive equalization.[6] In this approach, an adaptive transversal equalizer filter is used to track the fading multipath signals. Another approach is the use of multicarrier modulation, where the spectrum of the frequency selective channel is divided into a large number of parallel, independent, and approximately flat subchannels. One example of this is orthogonal frequency division multiplexing (OFDM). OFDM is a multitone system using a multiplicity of juxtaposed tones, transmitted at some rate R, where M independent tones in parallel will result in information transmitted at a rate of MR. These contiguous tones can combat ISI since the fading is flat for each tone over the entire ensemble of (independent) tones. In this case, the symbol transmission rate (R) is much smaller than the coherence bandwidth of the channel (the tones). Since a condition results in which the narrowband tones are subject to flat fading, there is therefore no ISI.

Spread-spectrum signals can also effectively minimize the effects of multipath distortion. For example, **Fig. 4** shows two received signals: one is a direct signal while the other is a multipath signal. If the multipath signal is delayed by one chip, it will be rejected by the receiver since it is no longer in sync with the timing of the reference source in the receiver. It is thus seen as "hash" by the receiver. MRF

REFERENCES

1. D.M.J. Devasirvatham, "Multiple Time Delay Spread in the Digital Portable Radio Environment," *IEEE Communication Magazine*, June 1987.
2. P. Monsen, "Fading Channel Communications," *IEEE Communications Magazine*, January 1980.
3. W.G. Newhall, *et al.*, "Using RF Channel Sounding Measurements to Determine Delay Spread and Path Loss," *RF Design*, January 1996.
4. J. Shapira, "Channel Characteristics for Land Cellular Radio, and Their Systems Implications," *IEEE Antenna & Propagation Magazine*, August 1992.
5. G.L. Turin, "Error Probabilities for Binary Ideal Reception Through Nonselective Slow Fading and Noise," Proceedings of the IRE, September 1958.
6. R. Lucky, "Automatic Equalization for Digital Communication," *Bell System Technical Journal*, April 1965, pp. 547-588.
7. R.S. Burington, *Handbook of Mathematical Tables & Formulas*, Handbook Publishing Co., 1958.

Learn The Benefits Of Thin-Film Chip Capacitors

SINGLE-LAYER THIN-FILM capacitors provide many benefits in high-frequency circuits. These surface-mountable components offer low effective series resistance (ESR), high quality factor (Q), good power-handling capability, and repeatable performance at frequencies through 40 GHz. A six-page application note from AVX Corp., "Benefits of Thin-Film Dielectric Chip Capacitors at VHF, UHF, and Higher Frequencies," provides insights into the fabrication and use of these tiny capacitors in a wide range of RF and microwave electronic designs.

Written by Barry Breen and Leonid Talalaevsky of the AVX Thin-Film Operation (Jerusalem, Israel) and Scot Tripp of AVX Ltd. (Aldershot, Hants., England), the application note focuses on the company's ACCU series of capacitors developed by AVX in conjunction with materials specialist Kyocera (San Diego, CA). As the note details, the basic manufacturing process for these capacitors is similar to that used for semiconductors, with metal layers deposited on dielectric substrates by means of magnetron sputtering techniques. Advanced plasma-enhanced chemical vapor deposition (PECVD) systems are used to produce the dielectric materials. The capacitors are fabricated in Class 100 clean rooms for defect-free components. Capacitors are constructed on special glass substrates using pure aluminum-copper alloy electrodes and low-loss, highly insulating silicon oxide and nitride dielectric materials. Metal electrodes are formed by photolithography, maintaining dimensional tolerances to within ±2.5 µm. The final chip size is controlled by microprocessor-programmed diamond dicing saws.

The application note reviews the key characteristics of the ACCU series capacitors, including the low ESR, tight dimensional tolerances, good thermal conductivity (for high power-handling capability), and low loss through millimeter-wave frequencies. It also covers the use of the capacitors beyond their self-resonant frequencies (SRFs) and how they offer certain performance advantages compared to multilayer capacitors at higher operating frequencies.

AVX Corp., a Kyocera Group Co., 801 17th Ave. South, Myrtle Beach, SC 29257; (843) 448-9411, FAX: (843) 626-5292, Internet: www.avxcorp.com.

A six-page application note from AVX Corp. provides insights into the fabrication and use of these tiny capacitors in a wide range of RF and microwave electronic designs.

Thin RF LDMOS FETs Offer Stable Output Power

THIN TRANSISTORS CAN PROVIDE superior RF performance, provided that a proprietary process is used to fabricate special RF lateral diffused metal-oxide-semiconductor (LDMOS) transistors. The proof is presented in a white paper from Agere Systems, "Improved Electrical and Thermal Performance of Ultra-thin RF LDMOS Power Transistors." Although silicon is not noted for its thermal conductivity, the four-page white paper reveals how the ultra-thin RF transistors can maintain reduced junction temperatures. Electrically, the reduced junction temperatures allow for higher output power and efficiency, as shown by DC current-voltage (I-V) and RF measurements.

The white paper, which is available for free download from the Agere website, explains how the proprietary process (which is not detailed) can produce semiconductor wafers with devices as thin as 40 µm, with device yields approaching 100 percent. Because typical LDMOS devices can dissipate on the order of 600 W/cm^2, leadng to substantial heating of the junction, these transistors are usually housed in copper-tungsten (CuW) packages which in turn are attached to thermal heatsinks. A large portion of the junction-to-case thermal resistance of packaged transistors comes from the temperature gradient across the transistor die, since the low thermal conductivity of silicon restricts heat flow. But with the ultra-thin LDMOS devices, a major reduction in the junction temperature takes place, resulting in a factor of two reduction in the junction-to-case thermal resistance.

The white paper provides plots for junction temperature, junction-to-case thermal resistance, normalized output power, and drain efficiency as a function of output power. The thin die yield almost 100 W output power at 895 MHz, with considerably more power than thinner devices for comparable gain settings.

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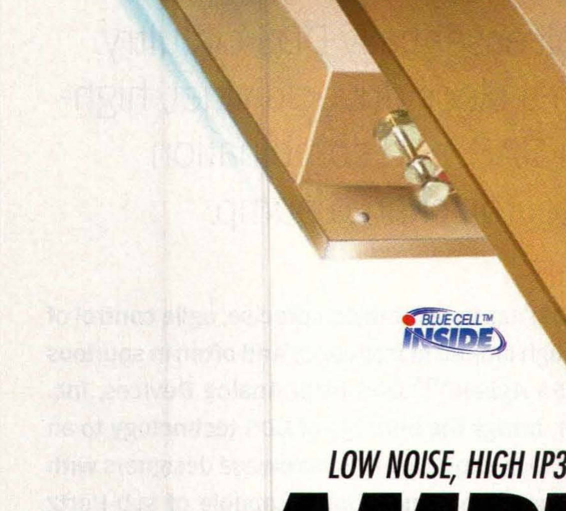

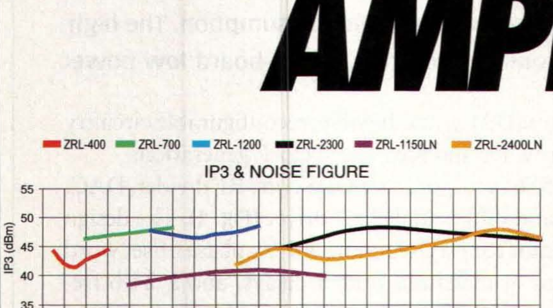

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ZRL-1150LN	500-1400	31	0.8	40	24.0	119.95
ZRL-1200	650-1200	27	2.0	46	24.3	119.95
ZRL-2300	1400-2300	24	2.5	46	24.6	119.95
ZRL-2400LN	1000-2400	27	1.0	45	24.0	139.95

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Integrated DDS Chip Takes Steps To 2.7 GHz

This highly integrated 2.7-GHz source includes all essentially DDS circuitry along with a clock driver, divider, high-resolution DAC, and combination phase detector/charge pump.

direct-digital synthesis (DDS) has long promised precise, agile control of output waveforms, although limited in frequency and often in spurious performance. The AD9956 *Agile*RF™ DDS from Analog Devices, Inc. (Norwood, MA), however, brings the benefits of DDS technology to an output range reaching 2.7 GHz, providing RF/microwave designers with a high-resolution, programmable signal source capable of sub-Hertz frequency resolution and microscopic current consumption. The high-speed DDS features 48-b tuning resolution, an on-board low-power 14-b digital-to-analog converter (DAC), and flexible, reconfigurable circuitry that can be used for both microwave and high-speed clock generation.

The highly integrated AD9956 incorporates a DDS core, RF divider, DAC, phase detector/charge pump, and differential clock driver **(Fig. 1)**. The design features a 48-b phase accumulator for precise tuning, a 14-b phase offset word to give designers a mechanism of matching system delays, and a 24-b frequency accumulator to provide a method of linearly sweeping between two frequencies. The instantaneous value stored in the phase accumulator represents the instantaneous phase of a sinusoidal frequency. On each system clock cycle the phase accumulator increments by a quantity determined by a value—the frequency-tuning word (FTW)—stored in a control register. The accumulator continues to advance its output value by the FTW until it overflows (i.e., surpasses its maximum value or capacity). A large FTW results in more-frequent overflows, thereby representing a higher frequency. In contrast, a small FTW leads to less-frequency overflows and represents a lower frequency.

The AD9956, with a 48-b phase accumulator, synthesizes a frequency, f_0, according to $f_0 = (Tf_s)/2^{48}$, where f_s is the system clock frequency, T is the value of the FTW, and $0 \leq T \leq 2^{47}$. Any change in the FTW value results in a nearly instantaneous, phase-continuous change in the output frequency. In addition to the 48-b of frequency tuning resolution, a 14-b phase offset register controls the phase of the output in increments of 0.22 deg. The accumulator output increases linearly and cannot directly represent a sinusoidal frequency. As the phase accumulates, the phase-to-amplitude conversion circuit converts

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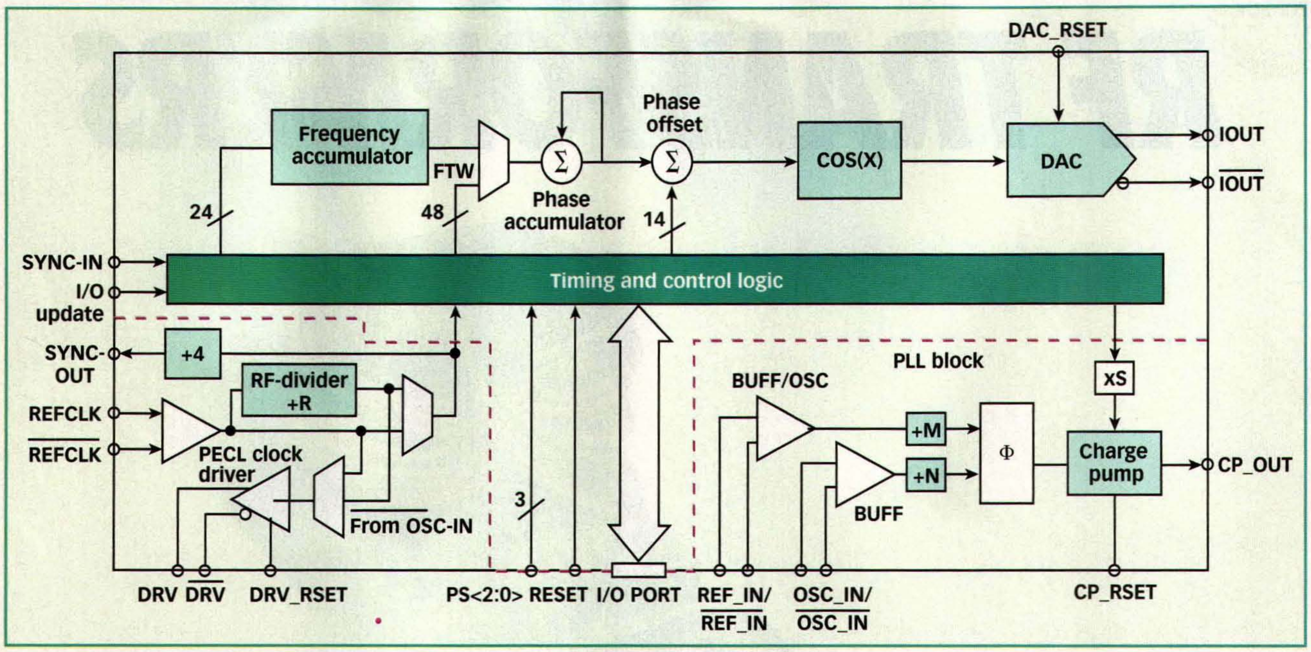
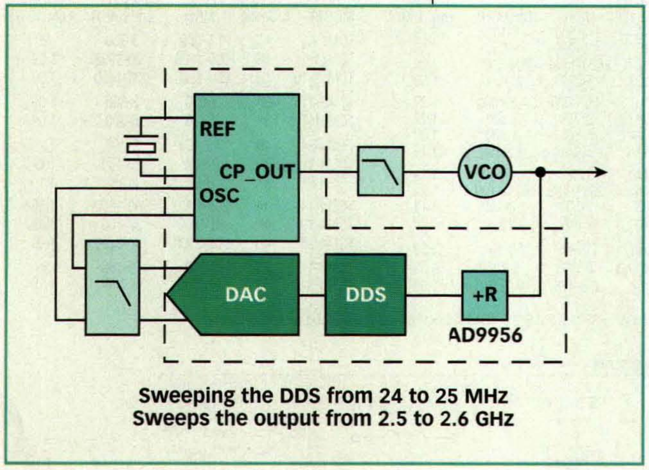


1. The AD9956 integrated circuit (IC) is more than just a DDS, as the variety of functions in this block diagram shows.

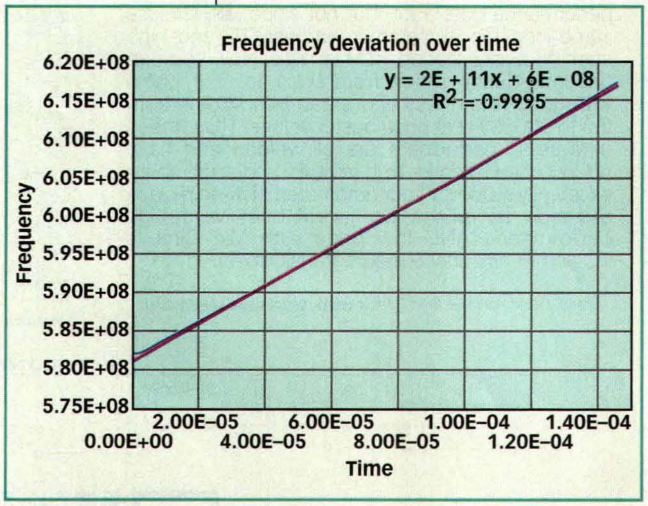
the accumulated phase to a 19-b representation of the amplitude of the sinusoid. Following the phase-to-amplitude conversion, the data passes to the DAC for conversion to an analog signal.

Obviously, the 14-b DAC cannot resolve all 48 b of the AD9956's phase accumulator's resolution. Furthermore, converting all 48 b of phase resolution to amplitude information would require a massive, power-hungry digital design. To minimize power consumption and die area, the AD9956 makes use of a subset of the 48-b phase accumulator by only taking the 19 most significant bits (MSBs) and truncating the remaining 29 b before going through the phase-to-amplitude conversion block. The truncation process produces repetitive errors in the digital signal which can show up as spurious content in the output spectrum. However, since the errors are algorithmic in nature, their placement and size are predictable. The magnitude depends on the capacity of the phase accumulator and the number of bits that are truncated. The DAC does not use most of the information contained in the least significant bits (LSBs) of the 48-b accumulator and so truncation generally does not adversely impact performance. The 14-b DAC limits the AD9956's overall spurious-free dynamic range (SFDR), and the spurious contributions are not noticeable if after truncation enough phase information remains to keep their energy below the DAC harmonics.

The AD9956 can also execute multichip synchronization and perform linear frequency sweeps thanks to its 24-b frequency accumulator. By programming start and stop frequencies into the AD9956 along with a step size (the delta FTW), the device can be made to ramp from start to stop frequencies in a linear fashion. The process is controlled externally by changing the state of the PS<0> pin from low to high. Clock generation represents one potential application of the AD9956, so a clock output that coincides with its system clock has been provided to help



2. This first circuit example, the AD9956 can be used to perform linearized frequency sweeps between a start frequency and a stop frequency.



3. Using the linear frequency sweep capability of the AD9956, the frequency deviations were plotted as a function of time.

designers synchronize its signal to other devices in their systems.

The reduced power DDS architecture of the AD9956 includes an important new feature with the addition of an RF divider at the clock input pins. The user applies a reference clock for the DDS and DAC at this divider port. Differential inputs are provided and are internally biased for ease of use. The input reference is the supply rail and provides a 1 V common-mode input range. A simple arrangement would require only AC coupling and the application of a reference clock source. Maximum input frequencies to 2.7 GHz are possible as the divider will bring the reference clock down to the DAC and DDS sample clock rate. The usable system clock frequencies fall in the range of 1 to 400 MHz. The RF divider is a programmable 3-b modulus-2 divider capable of dividing the input 2, 4, or 8 times, generating a low-phase-noise system clock for the chip. The AD9956's integrated DAC provides a 10-mA full-scale current and drives the analog output to about 500-mV pp differential signal when terminated with 25-Ω resistors. Highlights of the DAC include low power consumption, a 400 MSamples/s update rate, and 14-b resolution. A 1.8-V supply sets the DAC power consumption at 30 mW even while converting data at a 400 MSamples/s rate. The phase noise level is about –125 dBc/Hz offset 1 kHz from the carrier and reaches a noise floor of about –145 dBc/Hz offset 1 MHz from the carrier.

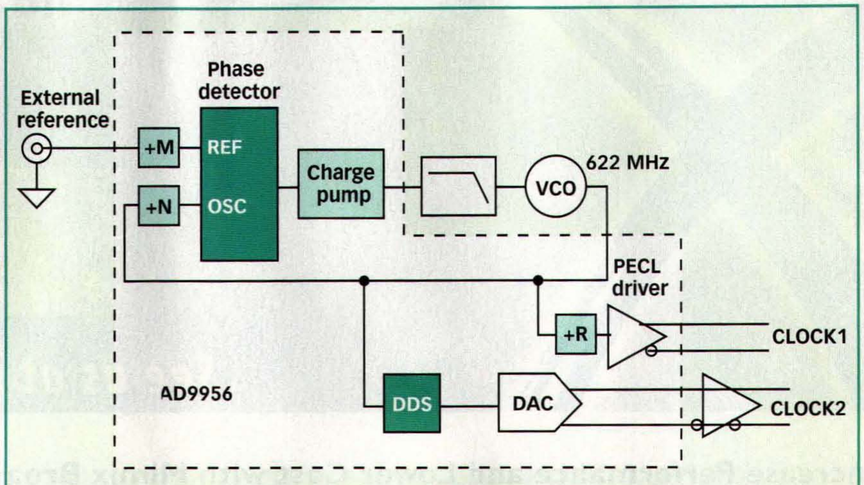
The phase-detector and charge-pump combination provides the necessary components to build a high-speed phase-locked loop (PLL) using voltage-controlled oscillators (VCOs) up to 650 MHz. At the inputs to the phase detector, programmable dividers divide incoming frequencies down to the maximum update rate of the charge pump and phase detector (160 MHz). Dividers at both the reference input and the oscillator feedback input are programmable in integer steps from 2 to 16 and may be bypassed when not needed. The charge-pump/phase-detector combination produces small spurs in the output spectrum at the reference frequency update rate, but since the phase detector operates at such a high a maximum rate, these spurious signals move well outside the PLL's closed-loop bandwidth where the filter greatly reduces their magnitude. The charge pump's maximum output current, which is programmable in 0.5-mA steps, is 4 mA. The high degree of programmability offered in the PLL components adds flexibility eases the task of optimization in the loop design process. Additionally, the AD9956 reduces the cost of generating a loop reference frequency by means of an on-chip oscillator that accepts 20-to-30-MHz crystals. Used in conjunction with the PLL components, the oscillator block offers a low-cost solution for the loop reference.

A 2.4-GHz VCO provides the clock input and the RF divider scales the VCO frequency by 1/8 to provide a system clock to the DDS and DAC. A filter reconstructs the DAC output which then feeds back to the phase-detector oscillator input where the phase detector compares it with the reference frequency. Reference signals can be generated by external sources to 650 MHz or by using a low-cost crystal in the 25-MHz range with the AD9956's on-board oscillator.

In addition to being a microwave synthesizer, the AD9956 also serves as a high-speed precision clock generator. With its precise tuning and ability to control phase accurately, a DDS makes an excellent clock source. Unfortunately, a traditional DDS is limited to output frequencies below one-half of the system clock rate due to the Nyquist criterion. However, since the AD9956 is actually a hybrid oscillator, with DDS circuitry, a PLL, and a clock driver, it overcomes the classic Nyquist limitation and can generate low-jitter clock signals to 650 MHz. The AD9956's high-frequency clock driver circuit generates differential clock signals with PECL output levels when terminated with a standard PECL termination arrangement. The configurable input operates to 650 MHz and drives a 50-Ω transmission line plus a 5-pF capacitance. Three configurations are available for driving the output, including configurations in which the phase-detector feedback input drives the clock output and in which the RF divider input or output drives the clock output.

Since clock jitter can limit the performance of a clocked analog-to-digital converter (ADC), the AD9956 was used to clock the AD6645 14-b ADC in laboratory tests. Using a low-cost 25-MHz crystal as the reference oscillator and putting the DDS in the PLL feedback loop, the AD9956 generated a 100-MHz clock to encode a 170-MHz analog signal. The measured signal-to-noise ratio (SNR) during the conversion was about –63 dBc, corresponding to less than 0.4 ps root-mean-square (RMS) clock jitter.

The AD9956's different circuit blocks

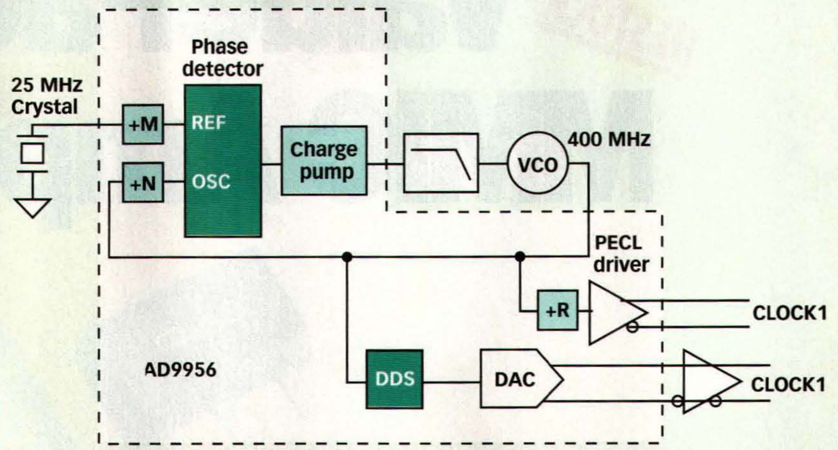


In this loop, M = 1, N = 16, and R = 4. The DDS tuning word is programmed such that Fout = 1/4 Fclk. Phase adjustments on the DDS output will skew the rising edges of the external comparator with respect to the rising edges of the PECL driver.

4. This second circuit example uses an external VCO to generate precision clock signals for wired and optical networking applications.

can be configured in numerous ways to yield different circuit configurations. While it is beyond the scope of this article to discuss this list exhaustively, four circuits will be covered. The first is a "fractional-divide" loop. Traditional PLL circuits have suffered from two fundamental limitations. First, because the dividers in the feedback path had integer values, the resolution of the loop was limited. Second, since a simple divider was used in the feedback path, the gain of the loop was static, limiting the ability to sweep the output frequency. Since the AD9956 can be used with the DDS portion of the chip in the feedback path of the PLL **(Fig. 2)**, the two traditional PLL limitations can be overcome. For one thing, the DDS is capable of fractional division. The VCO, operating up to 2.7 GHz, is fed to the RF divider of the device. The divided output, typically in the range of about 300 MSamples/s, serves as the system clock for the DDS. The DDS can then generate 2^{48} different frequencies from this clock, with 10-μHz tuning resolution. Because the DDS offers a linear sweep function, the divide value can be programmed to change over time, offering a linearized sweep of the VCO output. The sweeping profile can be configured by adjusting both the incremental frequency step size and the incremental frequency step rate.

It should be noted that since the ramping occurs in the feedback path, the VCO output will actually follow a 1/x(t) relationship, which is not truly linear. For any practical VCO with sufficient Q factor, the tuning range will be restricted to a region where this can be approximated as a very linearized response. In **Fig. 3**, a sweep is shown across a 35-MHz range and the covariance of the VCO output with a truly linear function is 0.995. A 35-MHz sweep at this intermediate frequency (IF) corresponds to a 4.29-GHz sweep at the transmitter. As an additional convenience feature, the reference input of the AD9956's PLL includes an oscillator circuit allowing the use of a low-cost but stable 25-MHz crystal. This swept function can be useful in a variety of military and automotive radar systems, such as vehicular systems using adaptive cruise control.



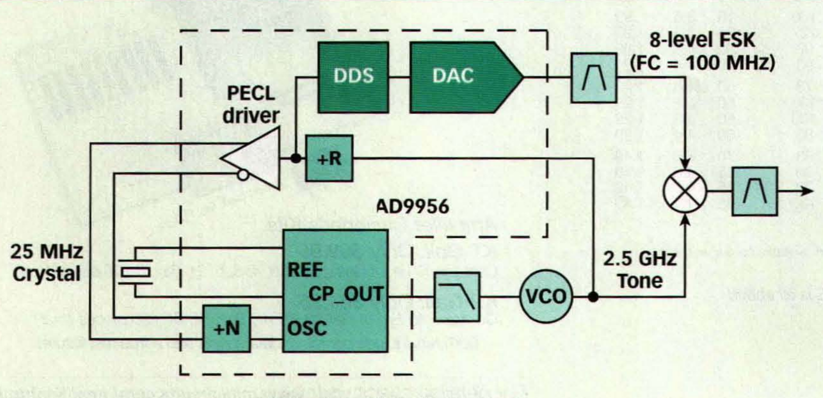
In this loop, M = 1, N = 16, and R = 4. The DDS tuning word is programmed such that Fout = 1/4 Fclk. Phase adjustments on the DDS output will skew the rising edges of the external comparator with respect to the rising edges of the PECL driver.

6. This fourth circuit example employs a 400-MHz VCXO to generate two different 100-MHz clock signals.

The second example circuit is oriented more toward network clocking applications. In an application such as this, the DDS is again used in the PLL feedback path to provide precision tuning. However, the VCO output is fed to the RF divider input and is also routed to an on-chip clock driver **(Fig. 4)**. The clock driver is a squaring device capable of operating to 650 MHz, so the VCO output must be kept at or below this rate in this configuration. The clock driver is actually a current output device, but when driving transmission lines terminated in 100-Ω impedances, a PECL voltage swing will be seen at the load (0.9 to 1.6 V). If a higher-frequency VCO is to be used, an external RF divider can be inserted into the feedback path to keep the clock driver input at or below 650 MHz. As with the first circuit, the oscillator section of the reference input of the PLL is enabled, allowing for the use of an inexpensive yet stable crystal as a reference frequency source. Because the DDS is capable of 48-b tuning, the frequency resolution of the output clock is about 4 $(Hz)^{0.5}$ (for a 400 MSamples/s clock). Preliminary investigation of the jitter on the clock driver, PLL and DDS indicate that the jitter in this loop is approximately 0.5 ps RMS. With its ability to provide clock signals to 650 MHz, the AD9956 is capable of clocking optical channels up to the OC-48 rate of 622 MHz.

The third example uses the DDS and the PLL separately **(Fig. 5)**. The PLL is con-

Continued on page 98



Objects within the dotted box are on-chip on the AD9956.

5. This third circuit example uses the AD9956's DDS and PLL circuitry separately to generate modulated output signals, including 8FSK and 8PSK.

PRODUCT *technology*

Module Melds FBAR Filter And CDMA PA

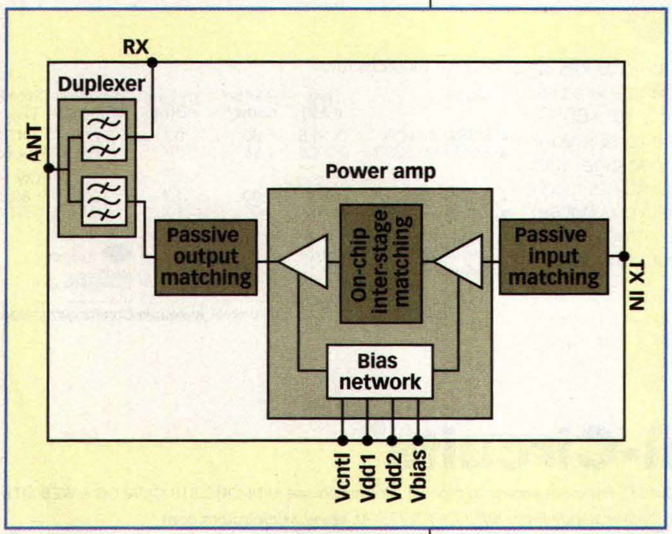
This front-end module (FEM) combines two key functions within a single compact and cost-effective package for CDMA 1900 cellular-telephone-handset applications.

JACK BROWNE
Publisher/Editor

Cellular-handset design is evolving toward higher integration and the use of more "plug-and-play" modules. In support of that trend, the AFEM-7731 front-end module (FEM) from the Wireless Semiconductor Division of Agilent Technologies (San Jose, CA) houses two vital cellular-handset components, the duplexer and the transmit power amplifier (PA), within a single package. Designed for code-division-multiple-access (CDMA) 1900 Personal Communications Services (PCS) and dual-band cellular handsets, the compact module provides the critical input and output matching to the PA as well as the impedance matching between duplexer and amplifier for ease of installation in handset designs.

The AFEM-7731 blends two of the company's key technologies. The duplexer, which is designed for transmit frequencies of 1850 to 1910 MHz and receive frequencies of 1930 to 1990 MHz, is fabricated with film-bulk-acoustic-resonator (FBAR) technology while the transmit amplifier, which delivers +24.5 dBm linear output power from a +3.4-VDC supply, stems from a GaAs enhancement-mode pseudomorphic high-electron-mobility-transistor (E-pHEMT) process highly regarded for its characteristic high power-added efficiency (PAE).

The duplexer's layout **(see figure)** provides high isolation, with receive noise blocking of 44 dB and transmit signal suppression of 54 dB. The duplexer's insertion loss is 2.2 dB in the receive band and 1.8 dB in the transmit band. The PA, which is designed to operate from a single positive voltage supply of +3.2 to +4.2 VDC, draws only 380 mA current. With fixed and dynamic bias control, the PA provides PAE of 40 percent. The FEM is supplied in a surface-mount-technology (SMT) package measuring 5.0 × 8.0 × 1.3 mm. **Agilent Technologies, Inc., Wireless Semiconductor Div.; (800) 235-0312, e-mail: semiconductorsupport@agilent.com, Internet: www.agilent.com.**



The AFEM-7731 CDMA 1900 front-end module (FEM) combines an FBAR duplexer and a GaAs E-pHEMT power amplifier in a package measuring 5.0 × 8.0 × 1.3 mm.

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Continued from page 92

figured more like a traditional PLL, using the included RF divider and the phase-detector divider to generate the frequency gain for the loop. The VCO operates at 2.4 GHz. This signal is fed to the RF divider and divided by 8, leaving a signal of 300 MHz. This signal is routed to the clock driver, which is externally connected to the feedback input (OSC) of the phase detector. The oscillator input has its own divider which can take divider values from 1 to 16. Placing the divider at 15 sets the phase-detector frequency at 20 MHz. The loop employs a 20-MHz crystal for the reference frequency. The 2.4 GHz tone is sent to the LO input of an external passive mixer. The 300-MHz signal also acts as the clock for the DDS. The DDS can be programmed with eight different frequency tuning words or eight different phase offset values, allowing for eight-state frequency-shift-keying (8FSK) or eight-state phase-shift-keying (8PSK) modulation. The DDS modulated output, which can be to 120 MHz, and can have a modulation rate of to 75 MHz, is fed to the IF input of the passive mixer. The result, after external filtering, is a low-cost ISM-band modulator capable of 8PSK or 8FSK to 2500 MHz, with modulation rates to 75 MHz.

Finally, the AD9956 can be configured to generate a different sort of clocking circuit. Many transceiver architectures employ an analog-to-digital converter (ADC) and a receive-side-signal-processor (RSSP) which require clock signals at about 100 MHz. The ADC clock must have very low-jitter (less than 1 ps RMS). The RSSP doesn't have the same jitter requirements, but it is very useful to be able to skew the rising edge of this signal with respect to the ADC clock rising edge. By using a 400-MHz voltage-controlled crystal oscillator (VCXO), the DDS and the RF divider can be employed independently to generate two different 100-MHz clocks with the ability to skew one rising edge with respect to the other with 14-b phase accuracy **(Fig. 6)**.

The low-jitter ADC clock is generated by sending the 400-MHz signal to the RF divider and sending the divided-by-four output to the clock driver. The undivided 400-MHz signal is also used to clock the DDS, which is also set to divide by four. The DDS has a 14-b phase offset word which can be used to adjust the rising edge of the RSSP clock signal with respect to the ADC clock. At 100 MHz, the skew resolution of this signal is 0.6 ps. Because only one clock driver is included on-chip on the AD9956, a second, external comparator would be required to square the output of the DDS. P&A: $20 (1000 qty.); 60 days. **Analog Devices, Inc., 1 Technology Way, Norwood, MA 02062-9106; (800) 262-5643, (781) 461-3333, FAX: (781) 461-4482, e-mail: ted.harris@analog.com, Internet: www.analog.com.**

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looking back

SEVENTEEN YEARS AGO, the microwave industry gathered in Rome, Italy, at the 17th Annual European Microwave Conference & Exhibition to share ideas on the growth of industrial systems and radar as well as the practical application of computer software in design.

next month

Microwaves & RF May Editorial Preview

Issue Theme: MTT-S Preview/Radar & Antennas

News

May's news section carries on one of the industry's richest traditions, with the most concise preview coverage of the annual IEEE Microwave Theory & Techniques Symposium (MTT-S). Scheduled for June 6-11, 2004 in Fort Worth, TX, the international event offers hundreds of technical presentations, along with a slew of new-product announcements and business transactions. Without wasting details, this show preview will efficiently present the key highlights of the regular technical sessions, panel sessions, workshops, and the RF Integrated Circuit (RF IC) Symposium technical sessions. It will also provide a sampling of the MTT-S exhibitors and their key product introductions.

Design Features

May's Design Feature section supports the radar and antenna theme with several informative technical reports. For example, a well-respected antenna designer shares his thoughts on a multiband antenna capable of serving both wireless-local-area-network (WLAN) and satellite-communications (satcom) systems simultaneously. Also, an author from South Africa explains how to design and specify antennas for minimum interference with installed applications. Additional Design Features will detail system-design considerations for microwave repeaters, explain how to make accurate in-phase and quadrature (I and Q) imbalance measurements on components during mobile-station manufacturing, and how to design a practical tracking generator for a microwave spectrum analyzer.

Product Technology

May's Product Technology section will debut a powerful signal analyzer capable of capturing and analyzing any form of modulated signal from 100 Hz to 8 GHz. The high-performance analyzer grabs signals as small as –156 dBm with resolution bandwidths as wide as 10 MHz. May will also include a detailed review on the industry's most practical filter-selection tool from a major supplier. Not only does it allow customers to experiment with trade-offs, it also provides S-parameter files for modeling purposes. Additional Product Features will explore a flexible PXI-based vector signal generator that operates to 2.7 GHz as well as a start-up company from Oregon with the industry's first complete WLAN conformance test solution.

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